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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AFIT/GOR/OS/80D-3	2. GOVT ACCESSION NO.: AD-A094854
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): HELBASE: A TOOL FOR THE ANALYSIS OF HIGH ENERGY LASER WEAPON DEVELOPMENT, DEPLOYMENT, AND OPERATION	5. TYPE OF REPORT & PERIOD COVERED: M.S. Thesis
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Jeffrey L. Dutton, Capt	8. CONTRACT OR GRANT NUMBER(s): Master's thesis
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Institute of Technology (AFIT-EN) Wright-Patterson AFB, Ohio 45433	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: December 1980
	13. NUMBER OF PAGES: 175
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

LEVEL

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release;IAW AFR 190-17 06 JAN 1981

Director of Information

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

FREDRIC C. LYNCH, Major, USAF
Director of Public Affairs

Air Force Institute of Technology (ATC)
Wright-Patterson AFB, OH 45433

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Laser, laser weapon, high energy laser, operation of laser weapon, high energy laser development, antisatellite, space defense, satellite defense.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A computerized simulation model was developed as a flexible tool to aid in the design, deployment, and employment decisions regarding high energy laser weapons. Only the "space defensive" and "antisatellite" missions are considered. The simulation models the physical processes of laser propagation and laser effects, and it includes a "first-order" optimization process for selection of weapons and weapon paths of maximum efficiency. It also includes

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a "many-on-many" engagement model to test the effectiveness of the weapons selected.

Target satellites include a set of four hypothetical systems representing "real world" possibilities. Weapon choices may be base on the surface of the earth, in aircraft, or in circular orbits. The user specifies weapon design characteristics as well as associated basing modes for each type of weapon to be deployed by the optimization model.

In addition to selecting the targets and defining the types of weapons to be used, the user defines the time allowed to accomplish a defined mission, and the percentage of each system of target satellites which must be negated. Rudimentary tactics for weapon employment are also allowed.

Validation, verification, and experimental designs for model use are discussed. Recommendations for model expansion are given.

AFIT/GOR/OS/80D-3

HELBASE:
A TOOL FOR THE ANALYSIS OF HIGH ENERGY LASER WEAPON DEVELOPMENT, DEPLOYMENT, AND OPERATION

THESIS

AFIT/GOR/OS/80D-3 Jeffrey L. Dutton
Capt USAF

AFIT/GOR/OS/80D-3

HELBASE:

A TOOL FOR THE ANALYSIS OF HIGH ENERGY LASER WEAPON DEVELOPMENT, DEPLOYMENT, AND OPERATION

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

Jeffrey L. Dutton, B.S.

Capt USAF

Graduate Operations Research

December 1980

Approved for public release; distribution unlimited.

Preface

Even though the author had some prior experience in the analysis of orbital parameters and satellite characteristics and capabilities, little knowledge or experience in the art of modelling, laser propagation or effects, or optimization techniques was brought to this effort. The learning process was therefore substantial, and for this the author is grateful to the following people:

Lt. Col. James H. Havey, Jr.-- For guidance in defining HEL weapon characteristics and in modelling the laser propagation phenomena.

Dr. Peter J. Torvik-- For making the laser effects data understandable.

Capt. William E. Wiesel-- For helping to clear the cobwebbs from around orbital analysis.

And last, special gratitude is accorded

Lt. Col. Edward J. Dunne, Jr.-- For his tactful guidance, advice, and counsel through the entire modelling process.

Thanks are also due the Space Systems Division of the Foreign Technology Division (Air Force Systems Command) for making the data available, and to Lt.Col. George Jumper, formerly of the Air Force Weapons Laboratory, for information concerning current Air Force efforts in this area.

Jeffrey L. Dutton

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Abstract

A computerized simulation model was developed as a flexible tool to aid in the design, deployment, and employment decisions regarding High Energy Laser (HEL) weapons. Only the "space defensive" and "antisatellite" missions are considered. The simulation models the physical processes of laser propagation and laser effects, and it includes a "first-order" optimization process for selection of weapons and weapon paths of maximum efficiency. It also includes a "many-on-many" engagement model to test the effectiveness of the weapons selected.

Target satellites include a set of four hypothetical systems representing "real world" possibilities. Weapon choices may be based on the surface of the earth, in aircraft, or in circular orbits. The user specifies weapon design characteristics as well as an associated basing mode for each type of weapon to be deployed by the optimization model.

In addition to selecting the targets and defining the types of weapons to be used, the user defines the time allowed to accomplish a defined mission, and the percentage of each system of target satellites which must be negated. Rudimentary tactics for weapon employment are also allowed.

Validation, verification, and experimental designs for model use are discussed. Recommendations for model expansion are given.

I. INTRODUCTION

This thesis is an operations research oriented look at part of the world of High Energy Laser (HEL) weapons applications. In this "light," the investigation of aspects such as cost effectiveness, cost benefits, weapon trade-offs, the strategy of deployment, the tactics of employment, mission accomplishment and various system optimizations are of primary interest.

This chapter includes sections which discuss the background associated with defining the need for investigation of these things, the general problem area to which this thesis is addressed and its specific objective, the scope and limitations of the analysis and the model, the assumptions made to make the problem tractable, the approaches to solving the problem and building the model, and the sequence of chapters which follow.

Background

Research and development concerning HEL devices, as would be expected for an infant technology with such long range promise, has experienced major funding and directional changes over the past ten years. The major thrust of Air Force effort in the seventies, (to demonstrate the feasibility of acquiring, identifying, pointing, tracking, and disabling an aerodynamic object from an aircraft) has apparently (Ref 1:32-66) given way to something new. The "space defensive" mission, with a real probability of a proof-of-concept demonstration being the first U.S. HEL battle station, has apparently moved to a high priority position in the competition for R&D HEL resources.

The perception of the level of Soviet effort in this area, along with their intentions and capabilities, has combined with a realization of U.S. strategic dependence on our space systems to warrant this shift in priorities within the Department of Defense (Ref 2:1-5; 3:317-323).

As more resources are expended in the effort to field a viable system to perform the space defensive mission, the decisions required in the system research, development, test and acquisition process become more crucial (Ref 4:98-100). To field the right system at the right time in the right place and for the right cost requires that the best decisions possible be made from basic research through systems acquisition. Toward this end, a flexible tool in the form of a systems model has been developed.

Problem

The nature of the research and development process leading to prototype hardware or proof-of-concept demonstration of HEL devices is certainly no less risky than that for other relatively new technologies. In the R&D process for HEL systems, decisions regarding the expenditure of resources for basic research, laboratory hardware, development of peripheral and support equipment, production of weapon prototypes, and the full production buy must be made with some degree of knowledge concerning the probable payoffs. Knowledge of probable payoffs in terms of beam power, beam size, propagation characteristics, device, size and weight, power requirements, etc. are certainly being weighed in the decision-making process. However, the combination of these measurable weapon attributes in satisfying a specific military objective or mission is perhaps generally less quantified.

If the objective is to develop and deploy an HEL weapon system for satellite defense, where do we put our money? We can say that short wavelengths, high efficiencies, good reliability, lightness in weight, large optics, high pointing and tracking accuracies, minimum costs, large energy storage capacityand the ability to command the weapon are all important in the design of HEL weapons to make up the weapon system. But how do we make trade-offs of conflicting attributes: For example, would it be cheaper to expend resources to develop a relatively long wavelength weapon which could be put into several lower orbits, or to perhaps go forward with research leading to shorter wavelength weapons which could be put into geo-synchronous orbits? If we are at the prototype stage, and are looking forward to a production contract, how many weapons should we buy and what are the best orbits to put them in? Would it be cheaper to expend launch vehicles to place them all at synchronous altitude, or perhaps to place a few more in lower orbits? Is there some combination of orbits which can satisfy the objective in some way "better" than any single orbital altitude? And, going a step beyond deployment options, what kinds of tactics are best suited for satellite defense?

The general problem of interest here is how best to examine the various attributes of HEL devices and deployment options as they relate to a specifically stated military objective.

Thesis Objective

The purpose of this thesis is to properly define the appropriate attributes of merit and to develop a simulation model which would give a decision maker a flexible tool in investigating the effects of these attributes on specific space defensive missions.

Scope and Limitations

Scope. This effort is limited to an analysis concerning satellite targets and HEL devices based on the surface of the earth, in aircraft or in orbit. The purpose of the model HELBASE is to "most efficiently" define the basing parameters for a constellation of weapons to meet the user-defined mission requirements under the constraints of user-supplied weapons characteristics, allowed basing options and tactics. Ground-to-space, aircraft-to-space, and space-to-space irradiation is allowed. This approach would apply to investigating the characteristics of both satellite defensive systems or strictly anti-satellite (ASAT) systems.

The user inputs allowed are Target Type Selections, Weapon Type Selections, Mission Data, and Battle Management Data.

The model's most singular characteristic is its flexibility as a tool for the operations analyst. This flexibility as an analytical tool requires a rather large number of user inputs, and this immediately places a number of responsibilities on the user. Since virtually <u>all</u> first-order variables related to weapon system versus target system engagement design are included in user inputs, the user must select the control variables and decision variables pertinent to the <u>specific application</u> (i.e. purpose) the user intends. In other words, some thoughtful experimental design is normally necessary before employing HELBASE. For instance, investigation of launch costs would require controlling Mission Data, Target Types, and probably Battle Management Data, and allowing the orbital selections of Weapon Types to vary along a range of interest. In this way, launch costs could conceivably be minimized. Another user may be interested in evaluating various battle tactics or rules of engagement. This could be done by controlling Weapon Types, Target Types and Mission Data, and then varying inputs associated with Battle Management Data.

So this flexibility of HELBASE will allow its use in the investigation of a wide range of problems related to the deployment and employment of HEL weapons against target satellites. This flexibility places a responsibility on the user to understand HELBASE functions and methodology before confidence can be placed in the results. In fact, both pre- and post-analysis steps are strongly recommended for the use of HELBASE. This will be discussed in detail in Chapter V.

Limitations. It cannot be over-emphasized that HELBASE will only provide a first order solution to the most efficient constellation of allowed weapon types to perform the mission defined. The greatest degree of approximation occurs in the modeling of laser propagation through the atmosphere, and in the modeling of the effects these beams will have on the targets. This degree of approximation is justified by the "first order" accuracy of HELBASE, and by the large number of laser wavelengths allowed.

Only circular orbits are allowed for the orbiting battle stations in the general optimization algorithm. Other than in the placement of HEL battle stations in the proximity of satellites to be defended, or the orbit matching of target satellites with highly elliptical orbits, the value of allowing elliptical orbits for HEL battle stations is difficult to substantiate. In addition, the extra two degrees of freedom in orbit selection (eccentricity and argument of perigee) make the general efficiency optimization problem much more formidable (see Appendix B). Input of specific elliptical orbits for weapons would seem to have value, and is discussed in Appendix B.

Obviously, only HEL battle stations are considered, although model expansion to include Charged Particle Beam (CPB) weapons would seem worthwhile (e.g. trade-off and comparisons between HEL and CPB weapons for a specific mission).

In the same light, the user will be restricted to defining only one weapon per battle station.

Last, the cost impact of launching the "most efficient" battle station constellation into the required orbits is entirely ignored, as are the fixed costs of using the first weapon of a particular type in building the constellation.

To summarize, HELBASE is intended as a first order approximation to the most efficient basing distribution, and considers only the satellite defense and ASAT missions.

Assumptions

Implied in the construction of the HELBASE optimization algorithm are the assumptions of zero launch and fixed production costs. Knowledge of this will allow a judicious user to design the model use experiment to compensate if necessary for a cost analysis.

In consonance with a first-order approximate solution, orbital mechanics assume point masses and no perturbations. Circular orbits are perfectly circular, the earth is a perfect sphere of radius 6,378.145 kilometers, and so on.

Battle stations do not maneuver in orbit nor change location on the ground or in the air. (That is, aircraft carrying HEL weapons are assumed to "orbit" a specific ground reference point).

There is no "phase relationship" between targets and weapons. However, there is information available (this information is fairly easily obtained) concerning phase relationships could be used to improve the deployed systems performance. (See Chapter V).

All "most efficient" orbits identified by HELBASE are considered feasible with available launch vehicles and sites. That is, user specification of a weapon type which involves placing 10,000 pounds in synchronous orbit will be considered feasible by HELBASE, but would be perhaps of small value to the user.

The vulnerabilities of targets are assumed to be accurate and reliable. (See Appendix A).

No thermal blooming will occur during atmospheric propagation (See Chapter V).

Last, and possibly most important, it is assumed that the input of weapon parameters by the user implies that the user can, at the time intended, solve all technical problems involving weapon production, required pointing and tracking accuracies, etc.

General Approach

In addition to a description of the general optimization function, the approach to the development of the HELBASE model will be summarized.

Approach to "Most Efficient" Weapon Constellation. A functional understanding of the process by which HELBASE defines the "most efficient" constellation of weapons to meet the mission requirements can be gained by following a simple case through the optimization process. The range of all user inputs in the model will be considered in Chapter II. Here we will consider the simple case of 1 target type (say 4 satellites) and 1 weapon type (say at 300 nautical miles) for explanatory purposes.

We first establish a sphere centered at the earth's center whose radius is the radius of the earth plus 300 nautical miles (or 555.6 kilometers). Our weapons must, by definition of the weapon type, be placed in orbits corresponding to great circles around this sphere. The second step is to calculate an average sighting density over the surface of this sphere by stochastically placing the target satellites into their orbits, and determining whether they can be "sighted" from each of 1650 points distributed uniformly over the surface of the sphere. This process is repeated many times to establish the average sighting density for each point. Once these are established, the great circle which offers the greatest average sighting <u>over the circle</u> is found. A battle station is then placed in that great circle (circular orbit). A check of whether this first weapon can satisfy the mission requirements is made by placing the targets and this weapon stochastically into their orbits and letting the weapon fire against the targets <u>over time.</u> If, at the end of the Target System Negation Time (specified by the user), all of the mission requirements are met, the existing system could conceivably meet the mission requirements, and no more weapons would need to be placed. If all mission requirements were <u>not</u> met, we would need another weapon. The average sighting densities would then be recalculated, with the effect of the first weapon being accounted for. The entire process is repeated until the mission requirements <u>can</u> be met. The result is a constellation of battle stations in 300 nautical mile orbits which "most efficiently" satisfies the user's mission requirements.

Approach to Model Development. The modular concept of model development was used to allow the development of the basic submodels of HELBASE before combining them into increasingly larger units. The basic development steps are documented by Shannon (Ref 19:23) and others, and include:

System definition
Model formulation
Data preparation
Model translation
Verification and validation
Experimental design
Experimentation
Analysis of output
Documentation.

The definition of the system under consideration is discussed in this chapter, and the logic flow reflecting model formulation is the concern of Chapter II. Data preparation involved some manipulation of the data and is explained in Appendix A. Verification and validation are the subjects of Chapter IV, and experimental design and analysis of model output are covered in Chapter V. Documentation of the HELBASE model is in the form of detailed comments included throughout the model. A copy of the Fortran program is contained in Appendix C.

Sequence of Presentation

Chapter II (Model Overview) discusses in detail the functions of HELBASE. Supporting analyses for model design and functions are contained in Chapter III. Chapter IV, Verification and Validation, reviews the procedures and checks which were undertaken to insure that the HELBASE model will perform in accordance with its stated purpose and within its scope and limitations. Experimental designs for model use will be discussed in Chapter V along with some representative demonstrations.

Conclusions and Recommendations, Chapter 6, includes suggestions for model expansion, and these suggestions are discussed further in Appendix B.

II MODEL OVERVIEW

This chapter presents the general characteristics and capabilities of the model HELBASE by focusing on the basic functional relationships. In addition to the overall model, the user inputs and each of the sub-models are described in terms of the general purpose and functions of each. The general underlying character of HELBASE is that the output weapon system will be capable of meeting mission requirements given <u>no</u> knowledge of the time of hostilities initiation, or location of targets at this time. That is, the mission could be accomplished with a random "starting time" for hostilities, and with the placed weapons also in random positions within their orbits or latitudes. There has been no attempt to relate the positions of the targets and weapons in time.

Functional Description

Before any description of the basic HELBASE functions can be of value, several terms used frequently must be defined.

Basic Definitions

1. Basing Mode: This term reflects the essence of HELBASE, and refers to weapon locations on the ground, in aircraft, or in spacecraft. The mean surface of the earth represents a single basing mode. The airspace above the mean surface of the earth constitutes the second basing mode. The third and last mode is actually a continuous set of alternatives, each representing a user selected circular orbit altitude.

2. Weapon: One HEL from a specific weapon type.

3. Weapon Type: A specific combination of a set of HEL weapon

characteristics and a basing mode. A set of weapon characteristics include beam power, beam wavelength, maximum length of time for each firing of a weapon, minimum time between firing operations of a weapon, maximum number of times each weapon is operated, maximum firing range, beam waist size, and a probability of weapon failure. A given set of the weapon characteristics is combined with a basing mode to form a weapon type. A note about the "maximum firing range" is apropos here. This quantity is not a limit defined by the inability of the weapon to negate a given target at a distance past this range as a result of insufficient power applied to the target. Instead, it is a rough limit offered to the user as a bound on the weapon's ability to acquire, identify, and track the type of target chosen by the user for that weapon. If these subsystems do not constrain the use of the weapon, the default value may be accepted.

4. Weapon System: The collection of weapons selected by HELBASE from the available weapons types, along with specific locational parameters for each weapon.

5. Target: A single specific satellite upon which a weapon may be trained and fired.

6. Target Type: A group of targets which are related by a common set of mission and orbital parameters.

7. Target System: The collection of all selected target types. For example, a target type consisting of four navigational satellites could form a target system.

8. Mission: The operational capability around which the weapon system is to be defined. Target type selections together with mission data serve to fully define the "mission."

9. "Most Efficient": As used to describe the functions of HELBASE, "most efficient" refers to the weapon system (collection of weapons in specific orbits or on specific latitudes) "built" by HELBASE. It is important to repeat that the model is intended to arrive only at a "first cut" approximation of the "best"weapon system. Therefore, the term "most efficient" is to be viewed in a first cut approximation sense. Without doubt, there are other systems of weapons that are more efficient However, their definition is beyond the intent of this first cut model.

User Inputs. The four categories of user inputs are Target Types, Weapon Types, Mission Data, and Battle Management Data. Each of these areas will be defined in terms of its variables and the effects it has on the functions of HELBASE. Table I depicts a summary of all inputs with the associated default values. Most of the information in this table is also applicable to the detailed analysis of Chapter III.

As defined earlier, a target type is a group of targets which are related by a common set of mission and orbital parameters. For example, two communication satellites in synchronous orbit may constitute a target type. For this developmental HELBASE model, the user is restricted to the selection of any combination of four target types which were constructed to be reasonable representations of the range of "real world" possibilities. The user may select any of fifteen (15) different combinations of target types to form the target system. There is currently no provision for inputting a target type of the user's design (see Figure 1).

As defined above, we need both weapon characteristics and a basing mode to specify a weapon type. A basing mode involves one selection (ground, air or space) and (for space) one additional specification for each basing mode desired. Selection of the ground mode limits the deployment

TABLE I

Dimensions of User Inputs

Input Category	Variable	Default*	Dimension
Target Types	(1, 2, 3, 4)	*	------
Weapon Types	Wavelength	*	Nanometers
	Power	*	Watts
	Wai[illegible] Size	1 M	Meters
	Total Firing Cycles	∞	-------
	Maximum Firing Time	∞	Seconds
	Recycle Time	0	Seconds
	Maximum Range	∞	Kilometers
	Probability of Failure	0	-------
	Basing Mode	*	-------
	Altitude	0 Ground 12 KM Air * Space	Kilometers
	Absorption Coefficient	*	---------
Mission Data	Target Types	*	
	Target Type Negation Percentage	.8	----------
	Target System Negation Time	*	Hours
	Target Type Priority	1	----------
Battle Management Data			
	Target Type	*	----------
	Target Type Firing Priorities	4	----------
	Irradiation Time Sorting	0	----------

*Note: An asterisk indicates a mandatory entry.

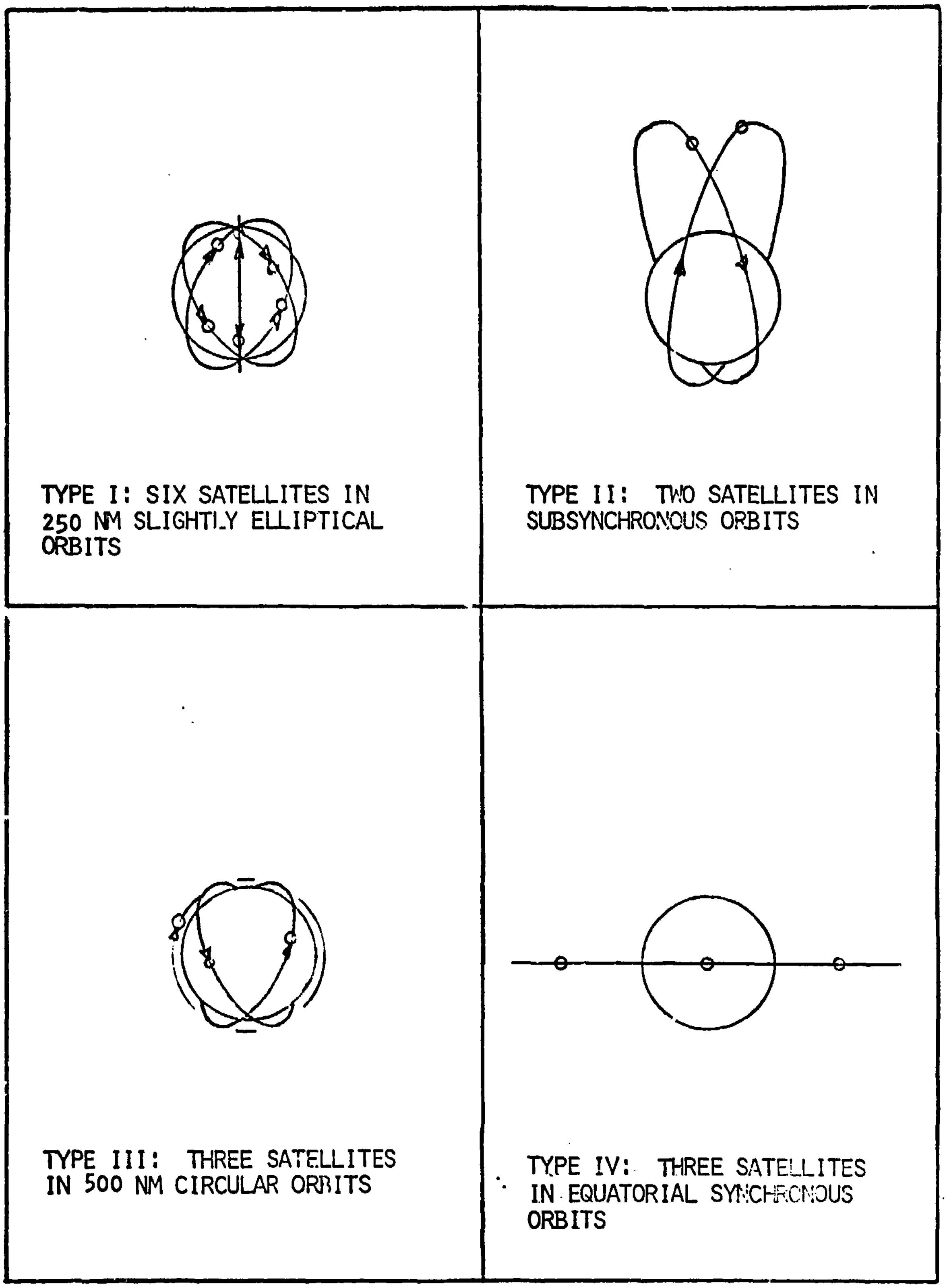


Fig 1. Target Types

of weapons with the associated weapon characteristics to any location on the mean surface of the earth. That is, HELBASE will deploy the weapons across latitudes so as to meet the mission requirements with the minimum number of weapons possible. Selection of the air mode will cause deployment of weapons in aircraft at 39,370 feet, again across latitudes. Selection of an aircraft altitude was judged to be of minimal importance regarding laser beam attenuation, and so the nominal altitude of 39,970 feet (12 KM). Selection of the space basing mode requires the specification of a circular orbit altitude in addition to weapon characteristics.

As a demonstration of multiple weapon type selections, assume a user has selected the ground mode with weapon characteristics set #1 and the space mode with weapon characteristics set #2 along with an orbital altitude of 400 nautical miles. A third selection is the space mode with weapon characteristics set #2 (again) along with an orbital altitude of 200 nautical miles. HELBASE would then select the "most efficient" combination of weapons from all weapon types to satisfy the mission requirements. This efficient combination may include some from each weapon type, or <u>all</u> from just <u>one</u> of the weapon types. The "most efficient" weapon system may include one weapon with weapon characteristics of set #1 at 55^{0} North latitude, no weapons at 200 nautical miles, and 4 weapons with weapon characteristics from set #2 at 400 nautical miles.

Mission Data inputs define the mission parameters under which the selected target types must be negated. A mission is not simply a matter of "melting all the targets in the shortest time possible" but rather "mission denial" (enough radiation on enough satellites to render the target type incapable of performing its mission) in a specified maximum length of time. Toward this end, the user inputs Target Type Negation Percentages, Target System Negation Time, and Target Type Priorities.

The Target Type Negation Percentage is the percentage of a particular target type which must be negated to insure mission denial. For example, we may have to negate six out of nine satellites of a particular target type (or .67) to insure that the target type could no longer perform its mission. A target type negation percentage must be input for each target type.

The Target System Negation Time is the maximum time the user will allow the weapon system to accomplish the mission. The target system negation time may also be conceptualized as the "maximum mission accomplishment time allowed."

Target Type Priorities are relative weights assigned to each target type, and are used to bias the deployment of the weapon system toward those target types with the higher priorities. That is, the resulting weapon system locational parameters (ground-and air-based latitude, space-based orbital parameters) and to a lesser degree the selection of weapon types will be biased in favor of negating the higher priority target types sooner. The priority weights are values of 1 to 1000. Note that this is a strategic concept, in that the deployment of the weapons is affected. This must not be confused with target type firing priorities, which is a tactical concept discussed below.

Battle Management Data inputs reflect the tactical concerns of the user. Options included in this HELBASE model are Target Type Firing Priorities and Irradiation Time Required. (Other options not included are listed under recommendations in Appendix B). The user may select either, neither, or both options.

If the user wishes to use the engagement tactic of assigning target type firing priorities, a priority of one is assigned to the highest priority target type and so on to the lowest priority target type. (An equal priority may be assigned to more than one target type). Assignment of these priorities will cause relative inefficiencies in the use of weapon power, but will tend to negate higher priority target types first. That is, at a given instant in time, a specific weapon may have a choice from many target opportunities. The target type firing priorities will cause this "target opportunity set" to be separated into groups. Further separation by irradiation time required is possible within each of these groups, if desired by the user.

This time is a function of distance to the target and target hardness. Obviously, the target requiring the shortest irradiation time would be negated first. If target type firing priorities are not also assigned, all the targets in the target opportunity set are ordered by least irradiation time. If priorities are also assigned, each priority group of targets is ordered by least irradiation time.

To recap, the user may select: 1) neither option (random selection from the target opportunity set); 2) either option (simple ordering by target type or by irradiation time); 3) or both options (target type sorting followed by irradiation time sorting within target types).

Functional Flow

A broad understanding of HELBASE functional flow may be gained by examination of figure 2. Again, the simple purpose of the model

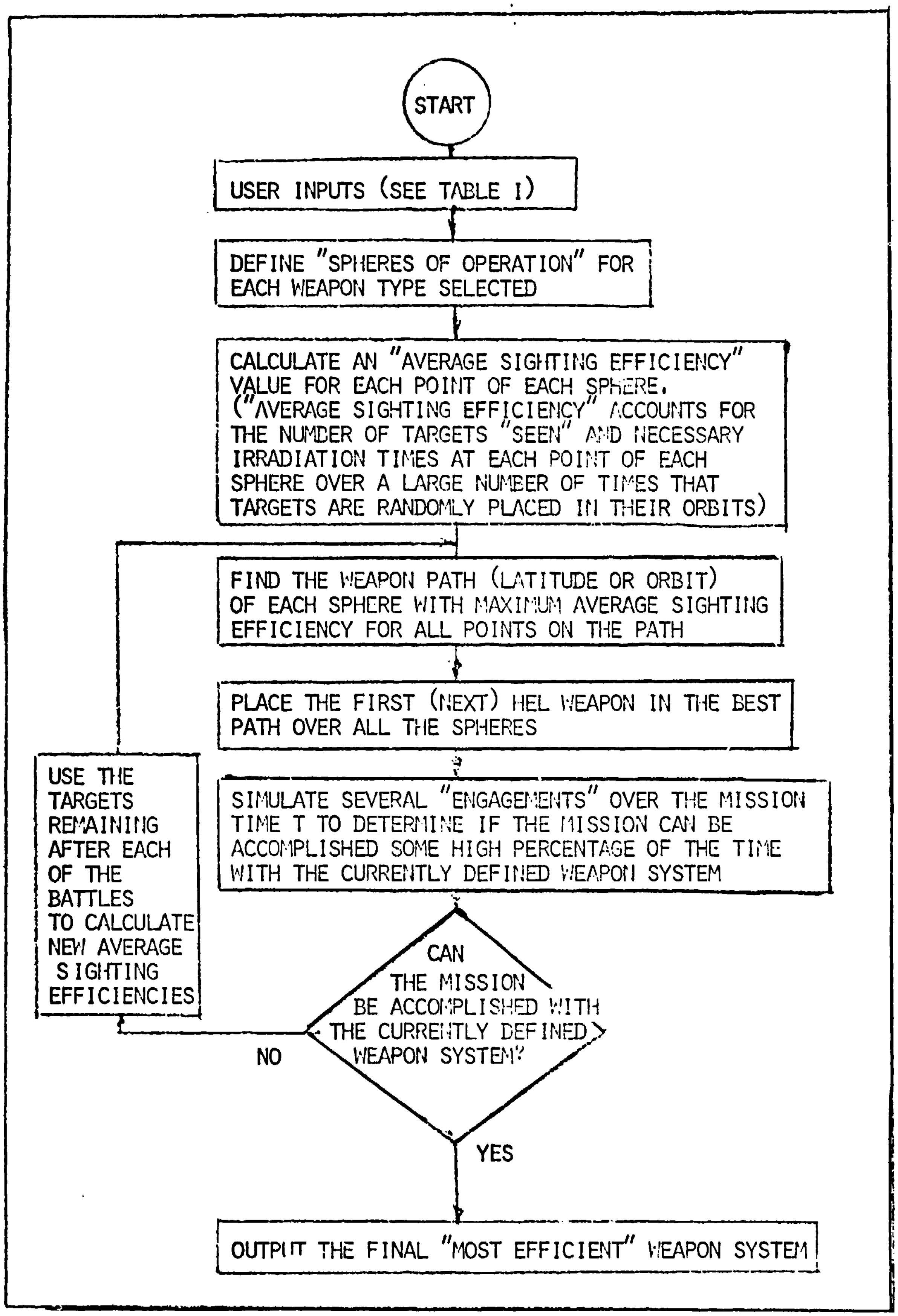


Fig 2. HELBASE Functional Flow

is to translate user inputs of targets, weapons, tactics, and the operational mission into a first-order approximation of the "most efficient" constellation of weapons required to perform the mission. "Most efficient" can be restated as the "minimum number" of weapons required to perform the mission. Again, just as the term "most efficient" is based on a first order approximation, the term "minimum number" is also approximate.

An alternate approach to understanding of HELBASE functional flow is presented in figure 3. The submodel SPATIAL is just the collection of SPHERE, TARGET, and SIGHT, all of which determine the three-dimensional spatial relationships needed. The submodel OPTIMIZE acts as the controller of HELBASE, directing all model activities toward the definition of the "most efficient" weapon system. The purposes of PROP (for propagate) and EFFECT should be apparent. BATTLE allows the weapons placed by OPTIMIZE to fire against the selected target system over the mission negation time.

Basic Physical Principles

The fundamental aspects of orbital mechanics, laser propagation and laser effects, as used in HELBASE, are described below.

Orbital Mechanics. As stated in Chapter I as an assumption, no perturbations in orbital behavior are considered. The earth is represented by its mass located at the center of a sphere of radius 3443.923 nautical miles (NM), or 6378.145 kilometers (KM). Distances are referred to in either NM or KM, but the model uses KM only. In the same light, earth satellite position is treated as the classic two body problem, with perfect elliptical orbits.

The coordinate reference system used is the geocentric-equatorial

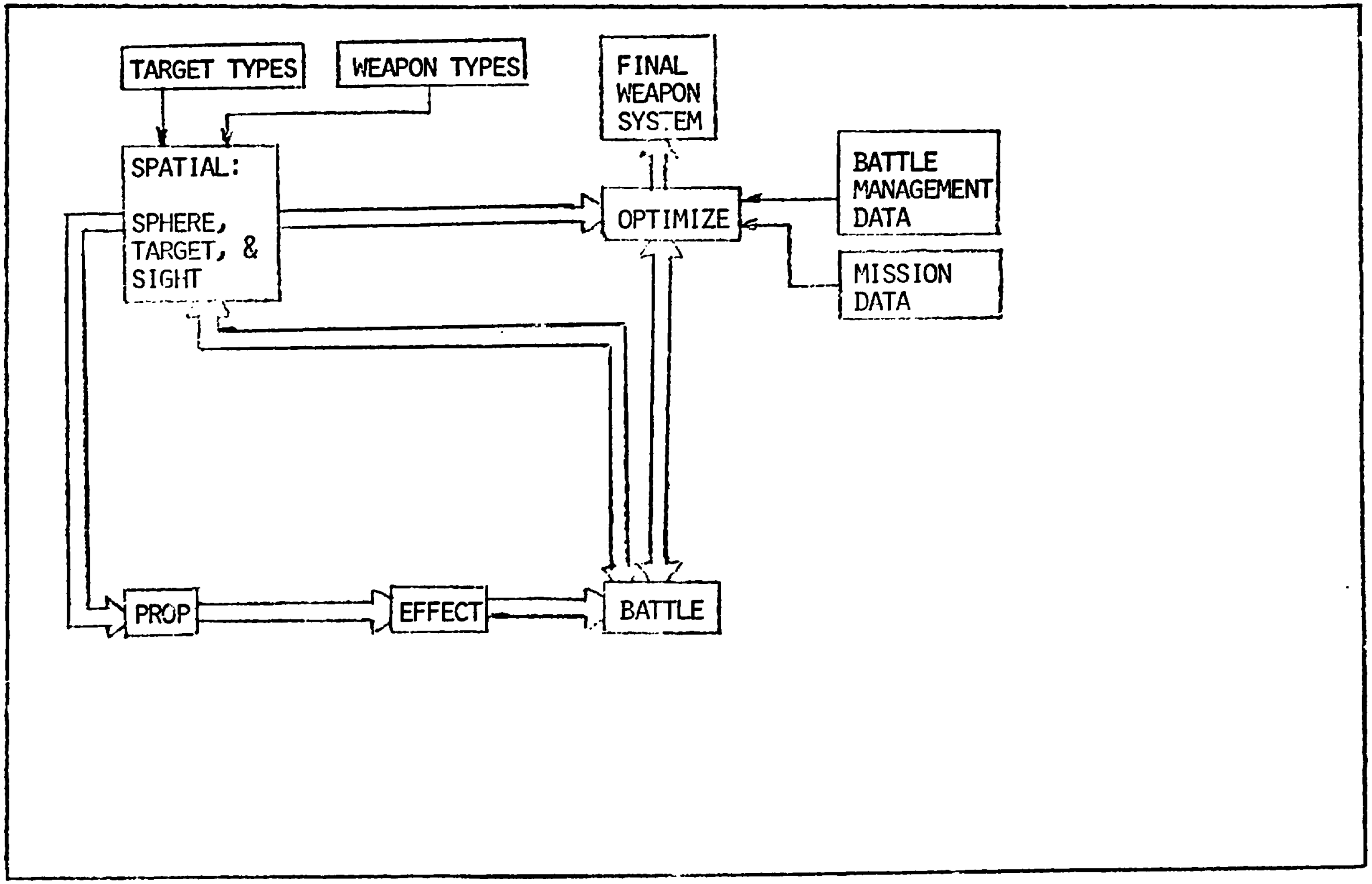


Fig 3. Alternate HELBASE Functional Presentation

system, which has its origin at the earth's center and is basically fixed with respect to the stars. This choice allows us to easily investigate the behavior of ground-based devices whose locations need only be represented by latitudes. Figure 4 depicts this reference system. Combining the assumptions above (simple two-body mechanics) with this coordinate system provides straightforward relationships between the target system and the weapon system. Satellites (both target and weapon) will have "stationary" orbits relative to one another, and weapons displayed on the ground or in aircraft will tend to rotate along latitudes below.

The uses of this reference system and orbital mechanics are restricted primarily to the random placement of satellites into orbits, and the movement of the satellites along these orbits through time.

The random placement of a satellite into an orbit means that five of the six orbital elements necessary to define the position of a satellite are held constant (see figure 4), and the sixth, mean anomaly, is selected randomly. The relationships needed for this random selection are as follows (Ref 5:185, 220-222).

M = mean anomaly. M varies uniformly from 0 to 2π.

E = eccentric anomaly. E does <u>not</u> vary uniformly, but as a function of the eccentricity of the orbit.

ν = true anomaly. True angle from perigee. (See figure 4).

Pertinent relationships are:

$$M = E - e \sin E \qquad \cos E = \frac{e + \cos \nu}{1 + e \cos \nu}$$

Note that random placement of satellites into their orbits is equivalent to randomizing the time at which hostilities begin.

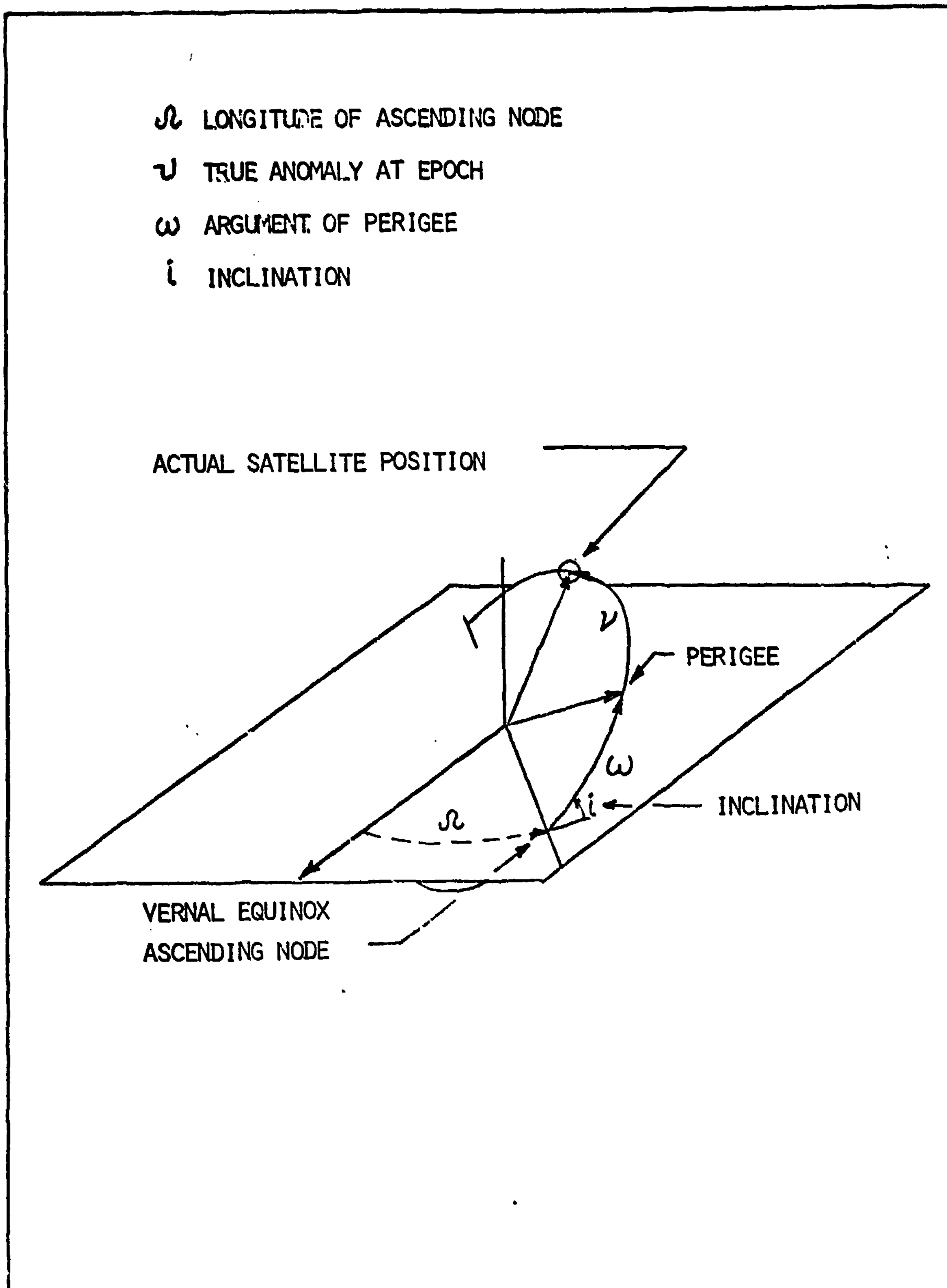


Fig 4. Geocentric Equatorial Reference

These same relationships are used to move satellites along their respective orbits in the submodel BATTLE.

Laser Propagation. As stated in the introduction, both the propagation and laser effects submodels form the lower accuracy bound on the performance of HELBASE. (See Chapter V for methodology suggested to increase the effectiveness of HELBASE). The laser propagation submodel PROP is based on accountability for the most basic two of the many atmospheric effects on a laser beam: beam expansion (of a collimated beam), and atmospheric attenuation (for the ground and aircraft modes only).

For propagation of a beam from a ground -, air -, or space-based HEL, expansion of the beam will occur as a function of the original "waist size" (Ref 7:17). This represents the initial beam radius (assumed TEMoo gaussian beam (Ref 8:94-97)) of a non-focused beam. The expansion of the beam also increases with distance from the device and with wavelength (Ref 7). A first order approximation for the radius of the beam of wavelength λ at a distance z from the weapon is given by

$$W(z) = W_0\left[1 + \left(\frac{\lambda z}{\pi W_0^2}\right)^2\right]^{1/2}$$

, where z is "large" ard w_0 is the initial beam radius at the waist mentioned above.

Laser beam attenuation (absorption) by the atmosphere can be expressed simply as a form of Beer's Law (Ref 7). We ignore the added effects of particulates and aerosols, accounting only for the decreasing density of the atmosphere as the beam propagates from the ground or aircraft toward the target and the water vapor present in the atmosphere. In general, we have

$$I = I_0 e^{-\int_{x_1}^{x_2} N(x)\,\sigma\,dx}$$

, where X is measured along a

direction of propagation perpendicular to the surface of the earth, N (X) represents the molecular density (molecules/cm^3) of the atmosphere as a function of X, and σ the mean molecular cross section coefficient for the wavelength considered (Ref 8). The above formula may be approximated by

$$I = I_0 e^{\int_{x_1}^{x_2} \sigma N e^{-x/8.5} dx}$$

This approximation is not accurate for particulates and aerosols, but it <u>does</u> allow the calculation of beam attenuation without finding N (X).

Chapter III contains a continuation of the derivation of the forms the above formula exhibits for ground - and air - based weapons. Both attenuation and expansion effects are combined in Chapter III in order to generalize the effect on beam intensity at the target.

<u>Laser Effects</u>. Generally, the effect (material changes) undergone by a target when irradiated by a laser beam is dependent upon the properties of the material being irradiated, the beam, and the physical relationship between the two.

Material properties at the initiation of laser irradiation are absorptivity, thermal conductivity, temperature, specific heat, density and latent heats of fusion and vaporization (Ref 7; 9:1-2). Beam properties of interest are wavelength, intensity and length of time the beam is applied. We will not consider, allow, nor model "pulse" lasers of such short duration and high power so as to cause mechanical pressure on the target. Conduction of the absorbed heat away from the target area is important in the case of longer irradiation times and lower power levels. Other complexities, such as the thickness of the material and the effects of melt retention and vaporization of the outer surface of the irradiated area, may also be considered for a specific application of interest.

Methodology for determining whether a HELBASE target is destroyed is contained in Appendix A.

Submodel Descriptions

Each submodel in HELBASE is functionally analyzed below. Basic interrelationships with other models are described along with the submodel inputs and outputs. In some cases a submodel may be used in slightly different ways by other submodels. The three submodels of SPATIAL, (that is, SPHERE, TARGET, and SIGHT), will be followed by the two submodels which deal with the laser beam, PROP and EFFECT. SIDEN (for sighting density) which is a part of the next model, OPTIMIZE, and BATTLE finish the list.

SPHERE. The purpose of SPHERE is to calculate and store the cartesian coordinates of 1650 points which define a "sphere of operations" (See figure 5). These 1650 points are spaced approximately 5^0 apart in latitude and longitude, and thus approximate a 5^0 uniform distribution of points over the sphere. This sphere of operations represents one of the basing modes input by the user. A 400 nautical mile (740.8 kilometers) circular orbit basing mode is represented by a sphere of operations of radius 3844 NM (7119 KM). The 1650 points are then spread uniformly over this sphere of operations, and each point represents an instantaneous weapon location possibility. Great circles around this sphere therefore represent possible weapon orbits.

It is important to state here that this sphere of operations is fixed in the geocentric equatorial coordinate system, so that, over time, the earth turns beneath the sphere. This restricts alternatives

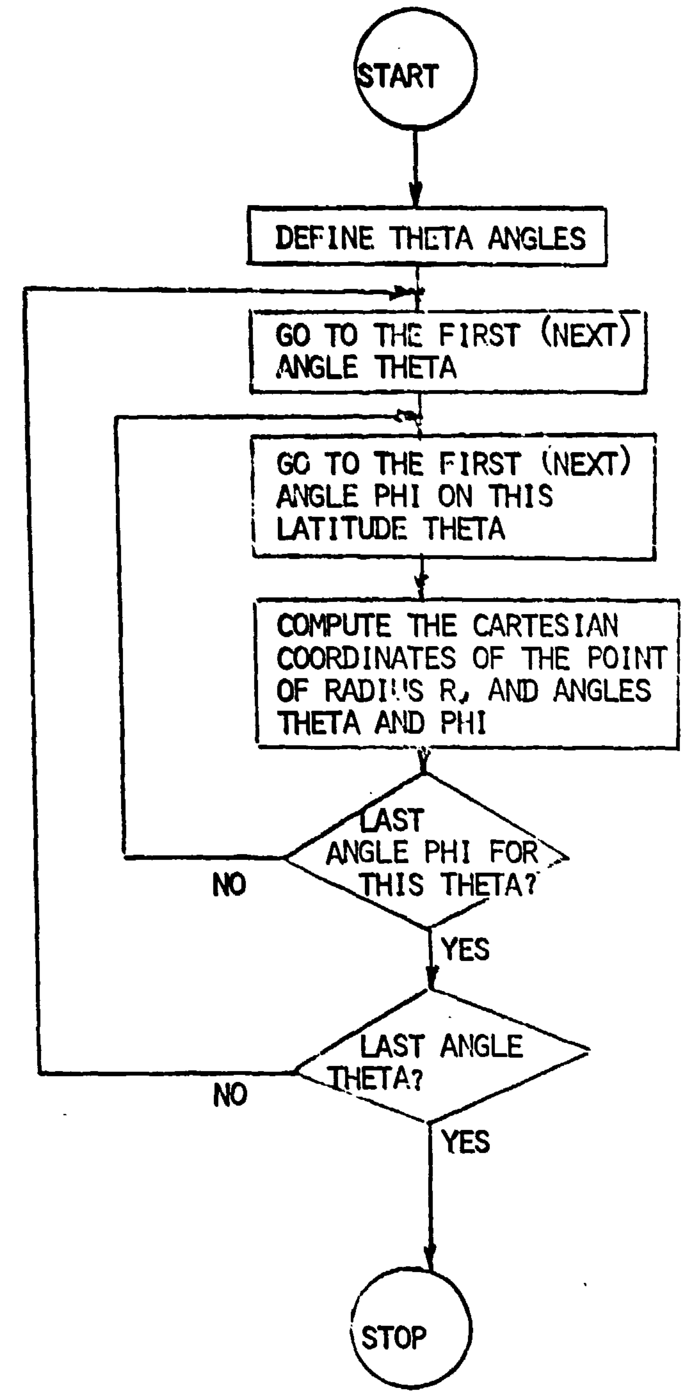


Fig 5. Submodel SPHERE

in the ground-based mode to latitude choices, and the spacing of our 1650 points in fact restricts our accuracy to 5^{0} latitudinal increments.

So SPHERE calculates and stores the cartesian coordinates of all 1650 points on a sphere of operations, which may represent the operational geometry of ground-, air-, or space-based weapons. A sphere of operations must be defined for each basing mode selected. SPHERE requires as inputs the radius of the sphere of operations, and outputs the cartesian coordinates.

TARGET. While SPHERE generates the operational geometry of weapon locational possibilities, TARGET does something a little different for the target satellites. TARGET simply places the targets into their proper orbits in a random manner, and stores the cartesian coordinates of all target locations. The TARGET algorithm involves a random selection of a mean anomaly from a uniform (0, 2π) distribution, a root solution to Kepler's equation for the eccentric anomaly, and then a simple conversion to the true anomaly, (See fig 6). Since TARGET stores the orbital elements for all four allowed target types, it only requires an input of which target types were selected. The output is the cartesian coordinates of each target in the target system (selected target types). TARGET, SPHERE, and two submodels not yet addressed are used by the next submodel, SIGHT.

SIGHT. Before we can discuss the purpose of SIGHT, we need to define a "sighting" as used here. Rather than the common understanding of an open line-of-sight between a point and the target, this "sighting" carries with it information about the feasibility of negating the target from the point in question. If we indeed have a feasible opportunity to negate the target, then we score a "1". If any of the variables which

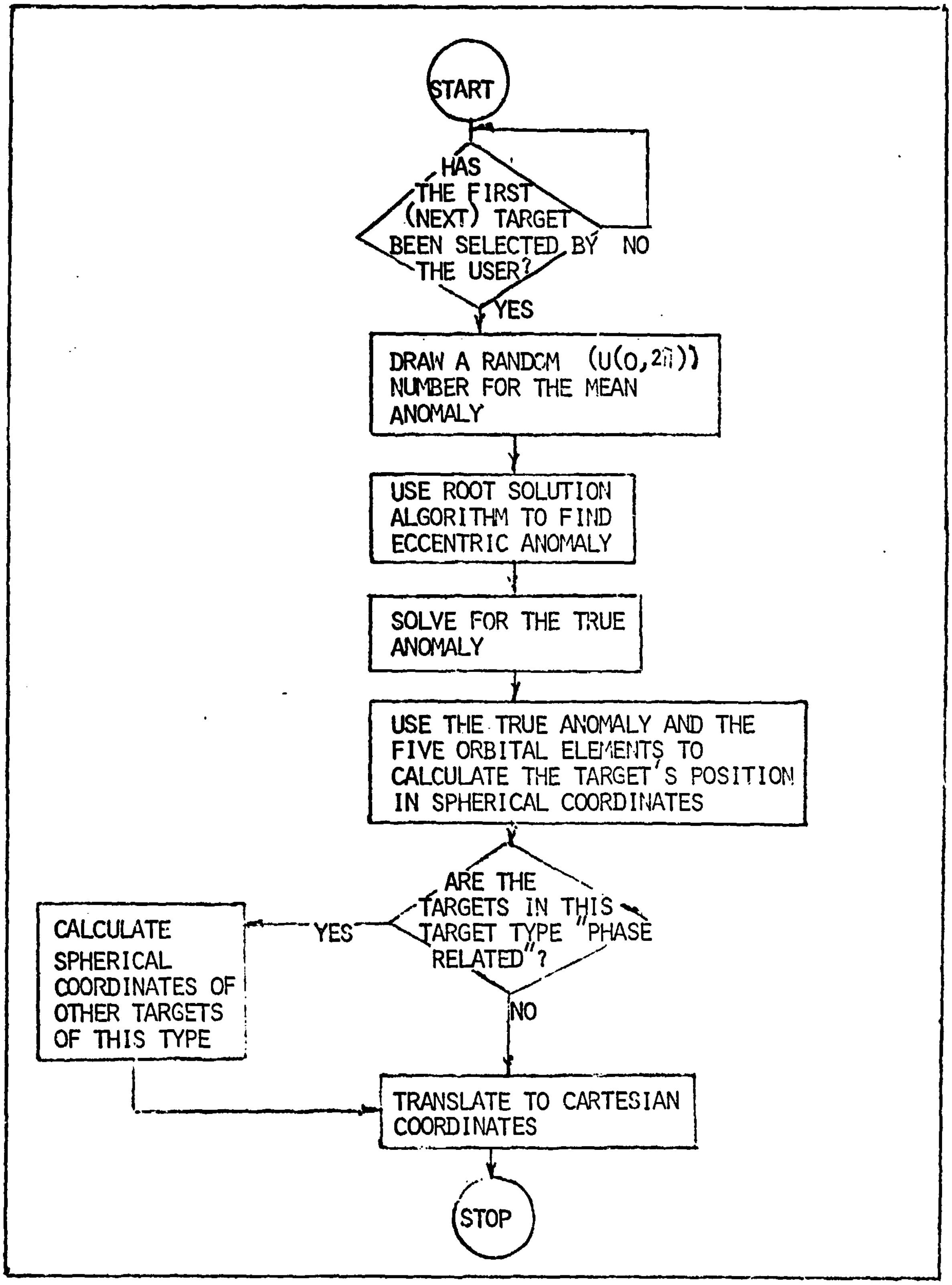


Fig 6. Submodel TARGET Logic Diagram

must be checked to insure a feasible "sighting" is a value which prohibits the negation opportunity, then we score a "Ø". Items checked to determine whether we have a "sighting" (feasible negation opportunity) are interference of the earth, maximum irradiation time restriction (for weapon power conservation), and maximum effective range. (See definition of range in "basic definitions" section).

To add a little more information to our binary "0, 1" score we divide by the irradiation time required to negate the target if the score is 1. This will allow a more efficient selection of weapon locations by OPTIMIZE. See Chapter II for the development of this attribute. So SIGHT provides <u>weighted</u> information concerning the <u>feasibility</u> of a negation opportunity for given target and weapons location. A value of Ø indicates that no opportunity exists, and increasing values indicate increasing power efficiency of feasible shots. See figure 7 for the SIGHT logic diagram. Required information is the location and type of the target, and location and type of the weapon. SIGHT will then provide the target sighting efficiency value as described above. SIGHT is used by SIDEN (a part of OPTIMIZE) and BATTLE.

<u>PROP</u>. This submodel, along with EFFECT, forms the lower bound on HELBASE accuracy. Depending on the use of HELBASE intended by the user, both propagation and laser effects modeled in PROP and EFFECT may need to be validated by the user and possibly expanded. (See Chapter V for details). However, for many uses the propagation and effects models described here are sufficient. (See Chapter III for formulation and supporting analyses).

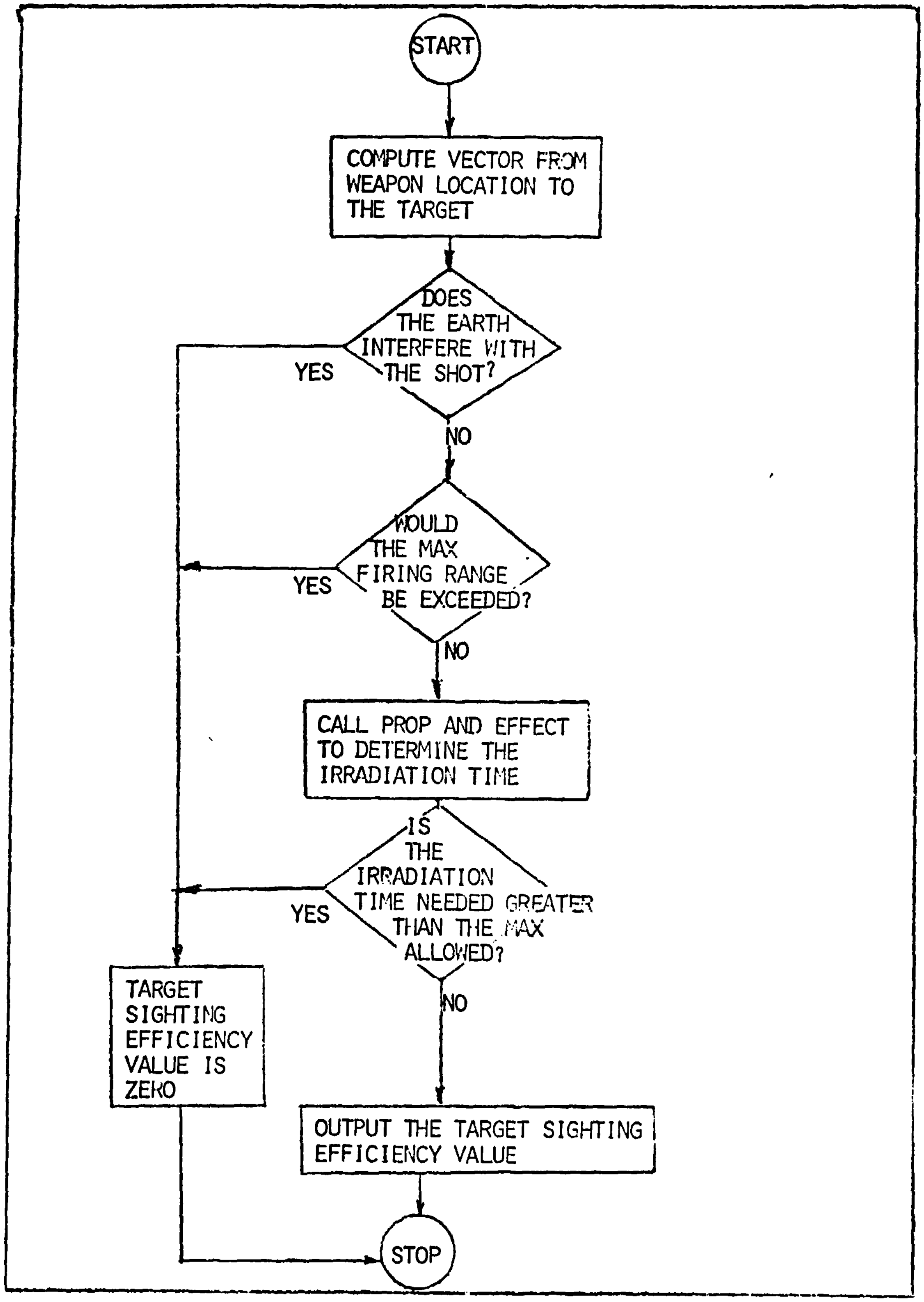


Fig 7. Submodel SIGHT Logic Diagram

PROP simply takes the wavelengths, initial beam intensity, beam waist size, and the geometry between the weapon and the target, and translates this information into an intensity of the beam at the target. Algorithms are included for ground to space, air to space and space to space beam spreading and attenuation.

EFFECT. In order to determine the irradiation time required to negate a target for which the beam intensity has been calculated by PROP, we use the submodel EFFECT. This model relies on a data base discussed in Appendix A. Assumptions and limitations of transforming this data to be used with an incoming wavelength, are discussed in Appendix A. With this data base, EFFECT uses the beam intensity at the target (and its wavelength) to calculate the irradiation time required to negate the target.

SIDEN. The purpose of SIDEN is to generate an "average target system sighting efficiency" value for each point on each sphere of operations. It does this essentially by using TARGET to randomly place the targets into their orbits and then using SIGHT to calculate the target system sighting efficiency of each point on each sphere of operations. This implies that SIGHT must be called for each target for one given point, and this process then repeated for all the points in that sphere and then for all spheres of operations. This information is retained and the target system drawn is thrown out and a new one drawn. Target system sighting efficiencies are again calculated and again new target system locations are drawn. This process is repeated until an "average target system sighting efficieny" value is reached for each point on each sphere of operations. The average target system sighting efficiency value then represents the percentage of all targets which can be "seen" from that point (on the average), weighted by the inverse of the irradiation time required. Chapter III provides the supporting analysis for this construct, and explains the rationale to use this value as a basis for weapon placement by OPTIMIZE.

The following explanations may help to clarify the meaning of this important efficiency attribute.

One weapon location looking at one target: Negation opportunity value or target sighting efficiency.

One weapon location looking at all targets in the system (as stochastically placed by TARGET): Target system sighting efficiency.

One weapon location looking at all targets randomly drawn many times: Average target system sighting efficiency.

These average target system sighting efficiencies are used for the deployment decision (by OPTIMIZE) of only one weapon. Once this weapon is placed, the efficiency values are no longer used. If another weapon is needed to satisfy mission requirements, a new efficiency must be calculated for each point. The new efficiency values incorporate the effect of the weapon (s) already placed by using as the target system the remaining targets at the end of a BATTLE (as opposed to using a complete target system as generated by TARGET) in the calculation of the target sighting efficiencies. Figure 8 is a logic diagram reflecting the functional description above. SIDEN is a major part of the OPTIMIZE submodel.

OPTIMIZE. As mentioned above, OPTIMIZE is the controller of HELBASE, and has as its primary function the selection of the "most efficient" placement of weapons in the basing modes selected by the user. It does so by the simple aggregation of the efficiency attribute "average

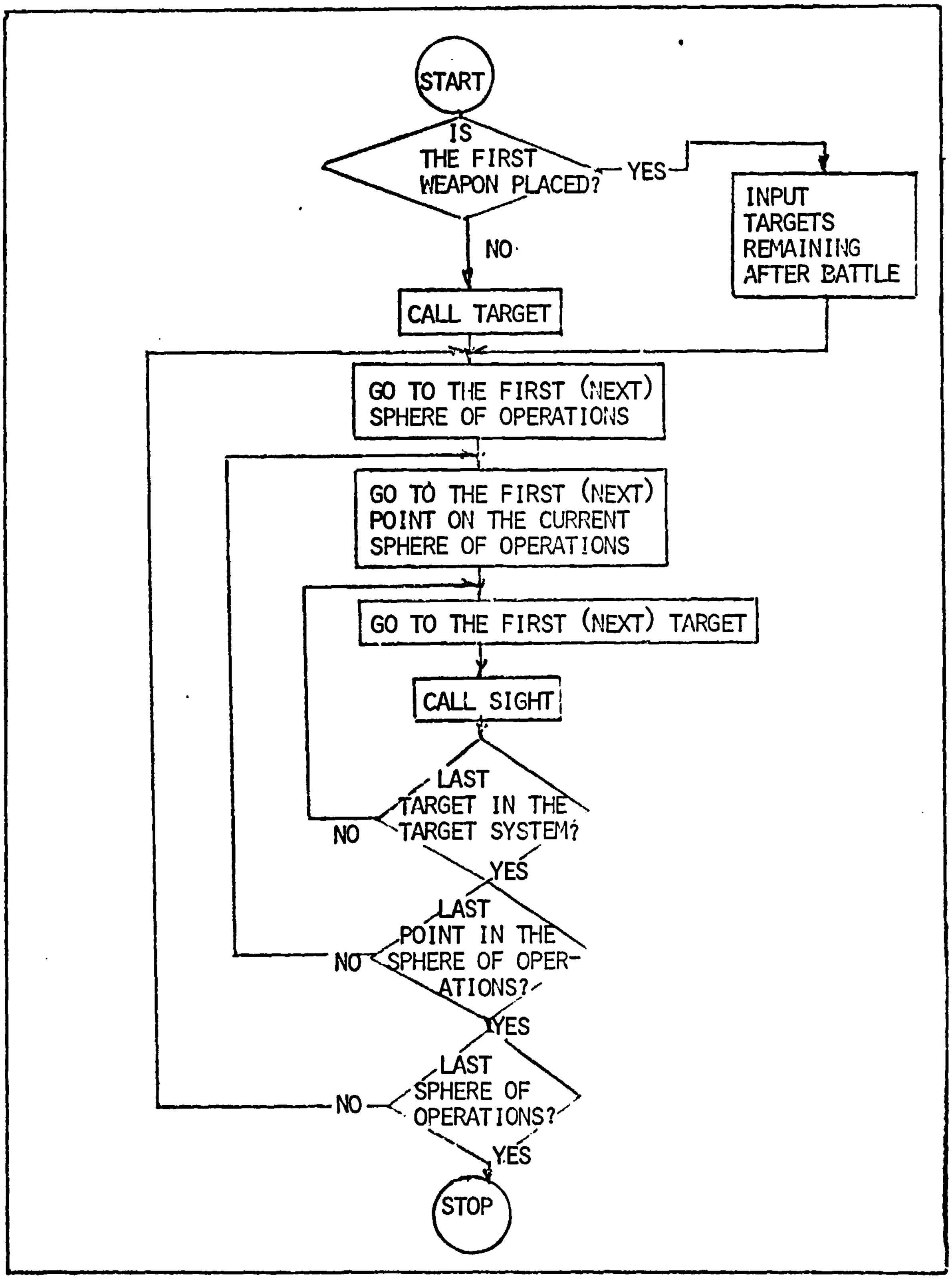


Fig 8. Submodel SIDEN Logic Diagram

target system sighting efficiencies" (discussed in the last section) around orbits (or latitudes for the case of the ground or air-based spheres of operations), and then selection of the orbit or latitude with the maximum aggregated value of average target system sighting efficiencies. Details of this selection procedure are provided in Chapter III.

In addition to placing the weapons, OPTIMIZE checks whether the weapon system consisting of all placed weapons can meet the mission requirements. This check is made by running a BATTLE for the mission negation time specified in mission data. If the mission requirements are met by the end of the mission negation time, the weapon system is considered sufficient to meet the user's needs. This check is made many times in order to develop some confidence in the ability of the weapon system to accomplish the mission. (Confidence interval statistics in Chapter IV) (See figure 9).

BATTLE. The only submodel which advances over time is BATTLE, which uses the weapon system supplied by OPTIMIZE to engage the target system over the mission negation time. In this submodel tactics characterized by battle management data are used.

The targets and weapons are randomly placed in their orbits or latitudes, the BATTLE clock is set to zero, and the engagement is begun within the constraints imposed by battle management data. The tactics available to the user are "target type firing priorities" and "irradiation time required." The user options are fourfold: 1) Let both tactics default (this would result in random target selection) 2) Assignment of target type firing priorities would cause targets to be ordered in terms of priority (target selection within priorities would be random) 3) The tactic of selecting targets by least to most irradiation time

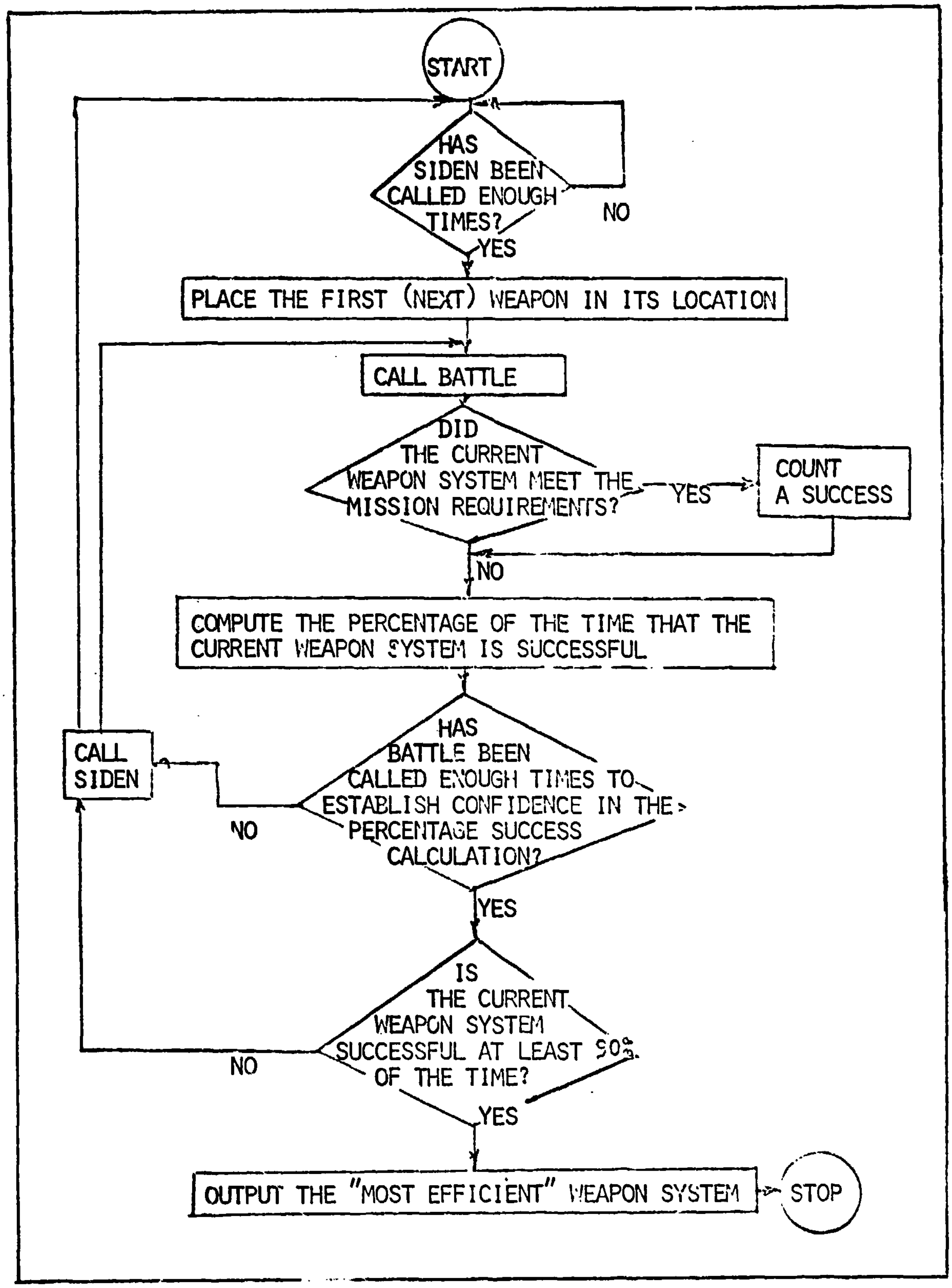


Fig 9. Submodel OPTIMIZE Logic Diagram

required without priorities would seem to be the most energy conservative of the four available tactics, 4) Last, the user may elect to sort the targets by priority and order by least irradiation time within each priority.

The above tactics, as selected by the user, are applied at an instantaneous time during the progress of BATTLE (See figure 10). This procedure incorporates a certain degree of approximation concerning the irradiation time versus the unallowed movement of both target and weapon during this time. The effect of this procedure is minimized by keeping the BATTLE clock advancement time on the order of some average irradiation time, say about five minutes. See Chapter III for a detailed analysis of BATTLE clock advancement time calculation. At t = Ø on the BATTLE clock, BATTLE must call SIGHT for all targets over all weapons. The irradiation times required for those shots that are feasible are recorded. The selected tactics are then employed to let the weapons fire against the targets. The BATTLE clock is then advanced, and all remaining targets and weapons are advanced a corresponding distance along their orbits (or along their latitudes). This process is repeated until the BATTLE clock reaches the mission negation time. OPTIMIZE then examines the results of the BATTLE.

This chapter is concluded with a table summarizing the HELBASE submodels, and their functions, inputs and outputs. (See table II). Chapter III forms the logical and mathematical rationale for the HELBASE functions described above.

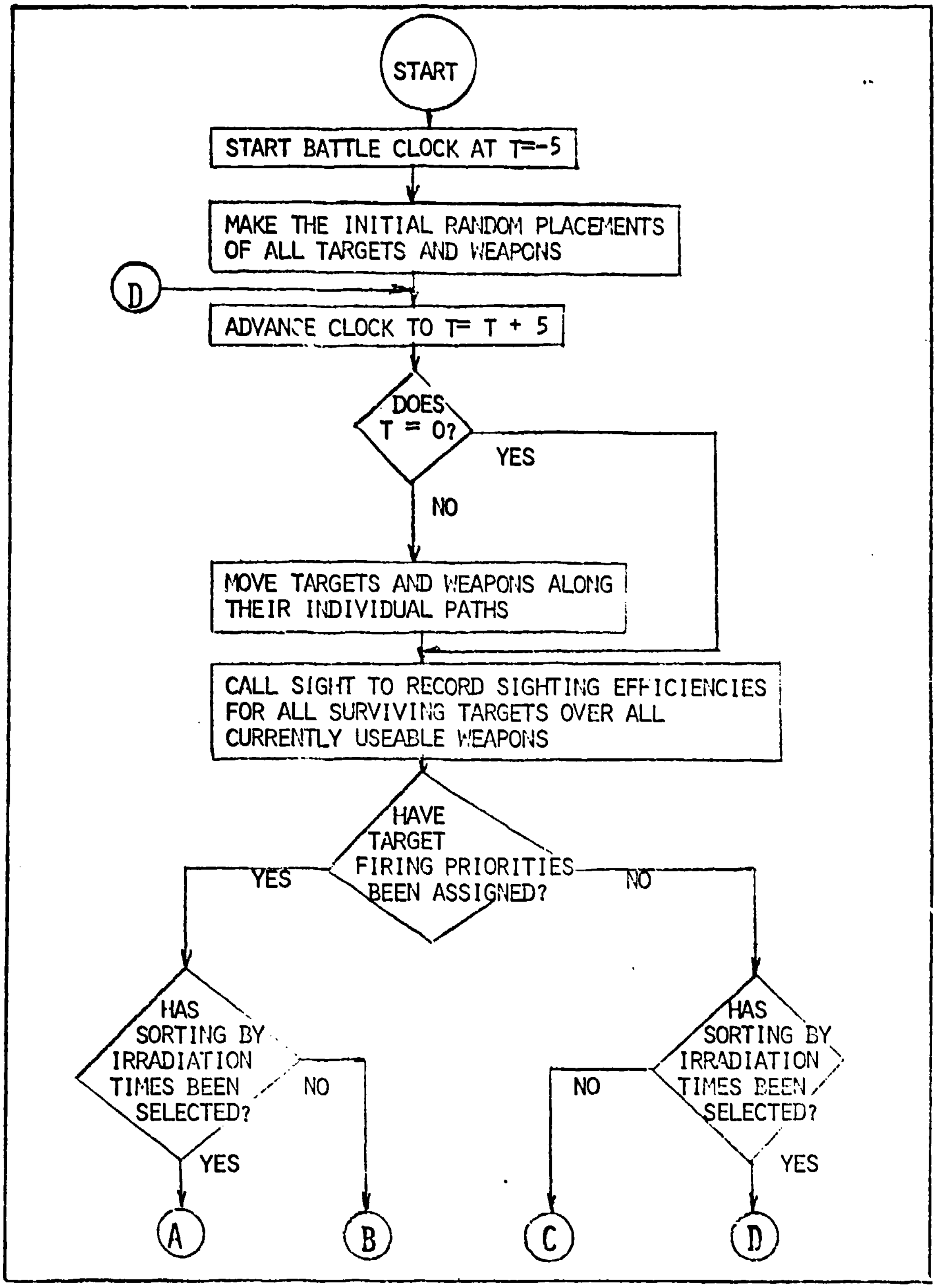


Fig 10. Submodel BATTLE Logic Diagram (1 of 2)

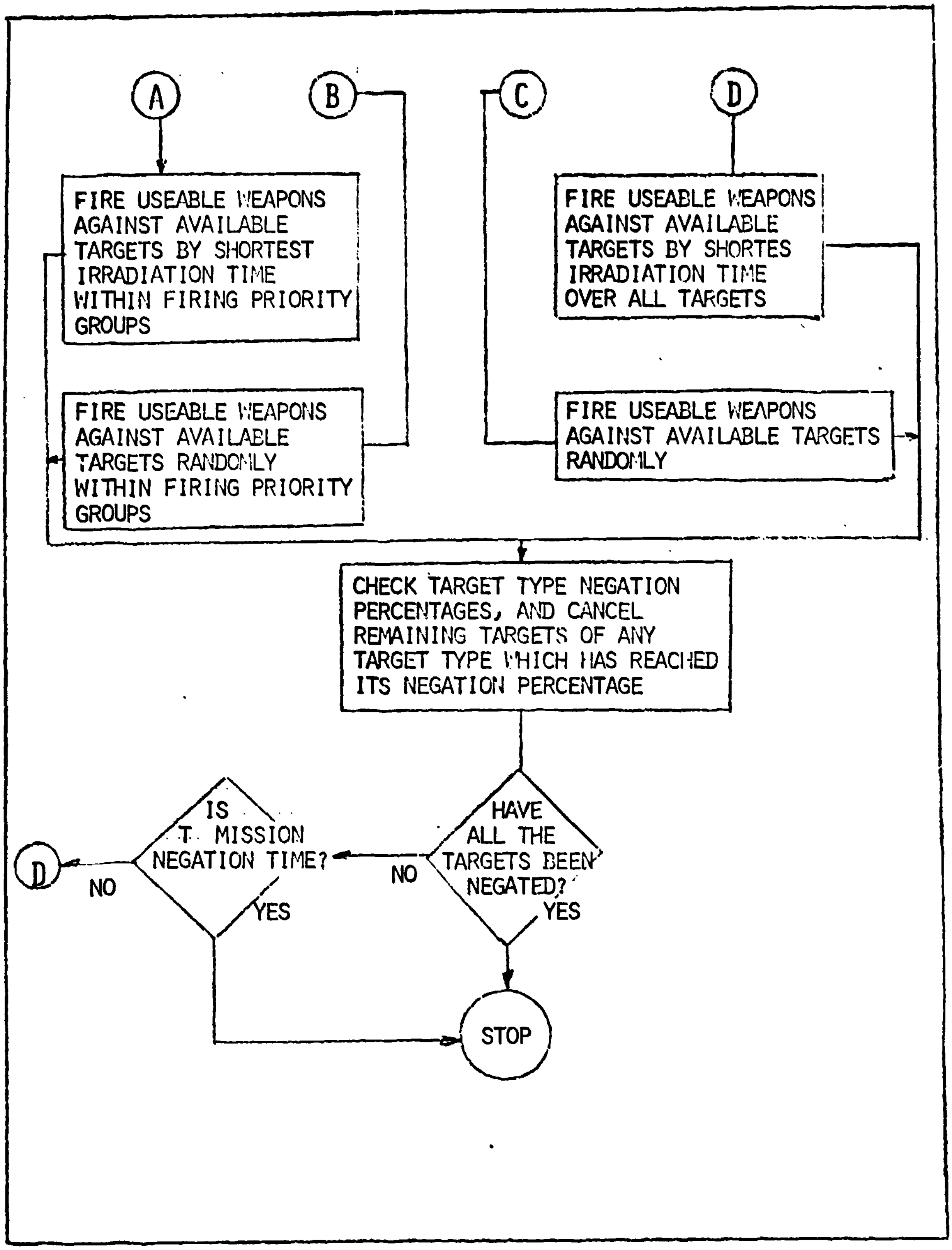


Fig 10. Submodel BATTLE Logic Diagram (2 of 2)

TABLE II

Summary of Submodel Functions

SUBMODEL	FUNCTION	INPUTS	OUTPUTS
SPHERE	Calculate and store cartesian coordinates of 1650 points on a sphere of operations.	Radius	Cartesian coordinates of all points.
TARGET	Place targets randomly into orbits.	Target type selections.	Cartesian coordinates of all targets.
SIGHT	Calculates target sighting efficiency.	Target and weapon location Weapon type and target type.	Target sighting efficiency.
PROP	Calculates beam intensity at the target.	Weapon type, weapon and target locations.	Beam intensity at target.
EFFECT	Calculates irradiation time required to negate a target.	Target type and beam intensity at target.	Irradiation time required.
SIDEN	Establishes the target system sighting efficiency for each point on each sphere of operations.	Weapon type, target type, spheres of operation.	Values of target system sighting efficiency.
OPTIMIZE	Select weapon orbits or latitudes and check mission requirements.	Average target system sighting efficiencies.	Weapon system locational parameters.
BATTLE	Engage targets over mission negation time in accordance with battle management data.	Weapon system, target system, mission data, battle management data.	Number of targets negated.

III MODEL DEVELOPMENT

This chapter contains the background analyses upon which various parts of the model are based. These derivations of various concepts and methodologies are included to support the functions of the model. Infrequently, methodological attempts which failed may be discussed as background material for those developments which were useable.

Sphere of Operations

The concept of a "sphere of operations," which is a stationary sphere in the celestial reference system, is used to represent all possible locations of a particular weapon type (see figure 11). It is a good approximation for ground-based weapons, slightly less good for aircraft-based weapons, and the most restrictive for space-based weapons.

Ground Basing Mode. For ground-based weapons, the sphere of operations is the surface of the earth. A ground-based weapon describes a latitudinal circle around its sphere of operations as the earth rotates 360° around its axis. Therefore, this path becomes a decision alternative (a possible laser weapon location) for the submodel OPTIMIZE (fig. 9). The continuous set of latitude choices is restricted to the discrete set of latitudes spaced at 5° intervals (see figure 12) for simulation purposes.

Aircraft Basing Mode. A similar idea is used for aircraft-based weapons, although the concept of latitudinal paths is not as accurate. The aircraft is restricted to "orbiting" a ground reference point during weapon operation, so that its path also approximates a latitudinal circle as the earth turns beneath the sphere of operations. Obviously

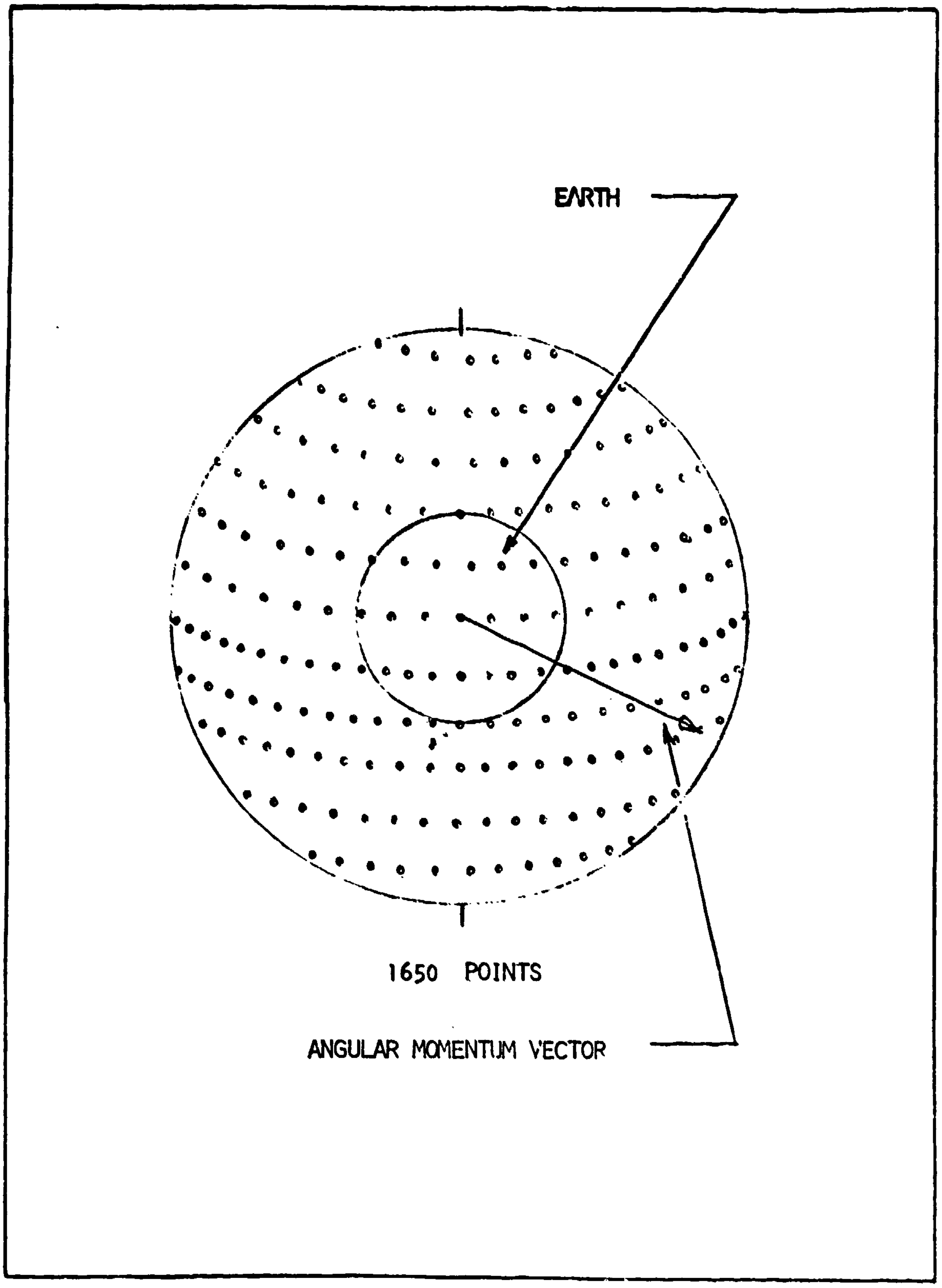


Fig 11. Sphere of Operations (Typical)

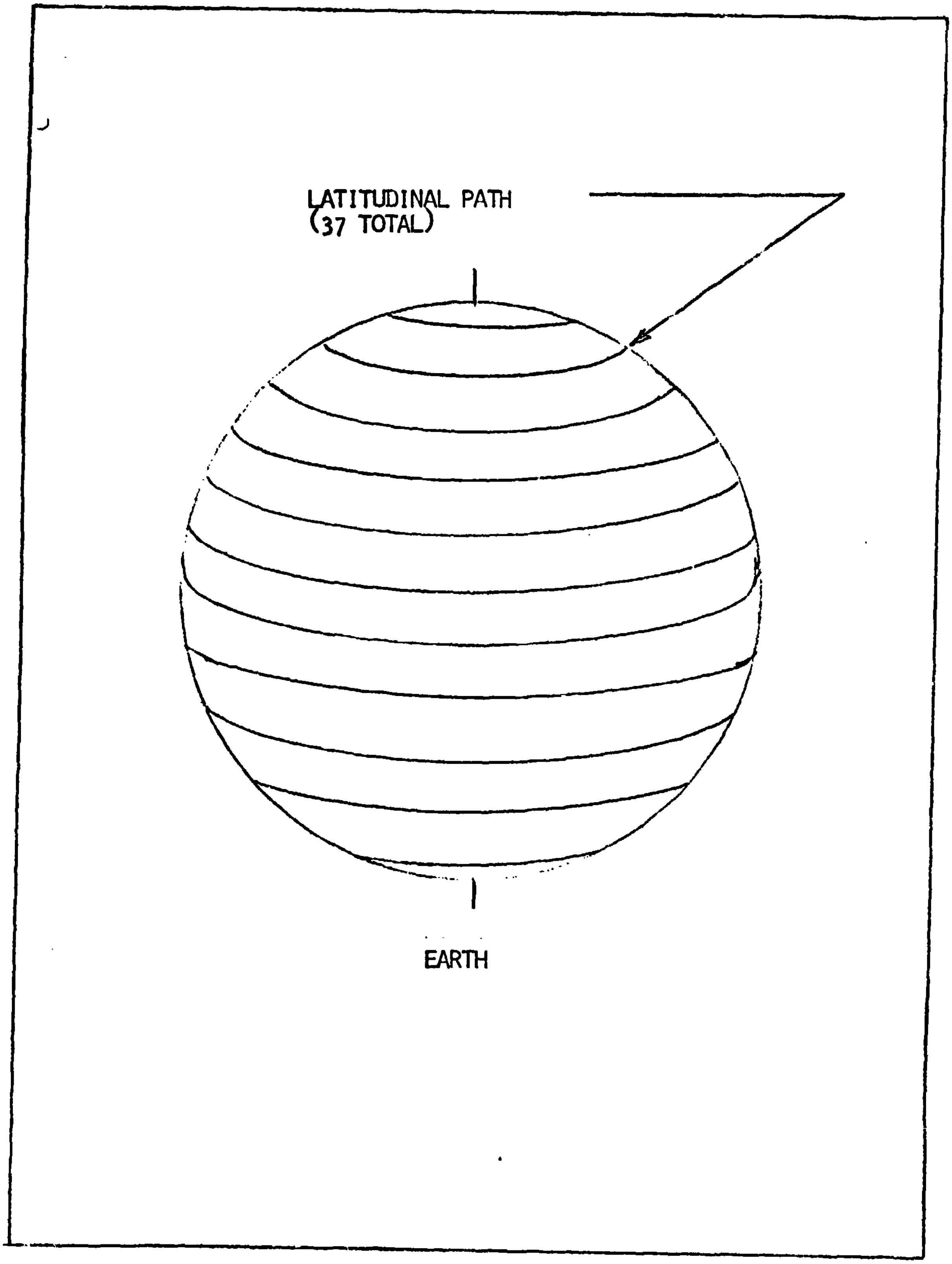


Fig 12. Ground-Based Alternative Latitudes

an aircraft traveling at 450 knots could cause some deviation from the "latitudinal circular path" concept, particularly at higher latitudes.

This restriction on aircraft movement is conservative in relation to the weapon system needed to meet the mission requirements. Chapter V discusses the analytical improvement of weapon system performance which may be obtained by removing this restriction <u>after</u> the simulation has placed the full weapon system.

<u>Space Basing Mode</u>. A sphere of operations for a space-based weapon is defined by a given radius from the earth's center. A continuous set of circular orbit possibilities is approximated by 825 orbital possibilities spaced approximately uniformly over the surface of the sphere of operations. Each of these 825 orbital alternatives is defined by a unit momentum vector, each pointing from the center of the sphere of operations to one of the 825 points. (fig 13).

<u>Placement of Points</u>. The original intent was to define a uniform spherical distribution of points, each a distance of five arc degrees from its nearest neighbors. After a search for and an attempted development of an exact three dimensional function revealed the limitations of the class of regular polyhedrons, an approximation was calculated as follows.

For each latitude, beginning with the equator as the first latitude and proceeding North in five degree increments, a "nearest latitude" was found which allowed an integer number of five degree arcs (whose length was defined at the equator) to be spaced around its circumference. For example, the equator, at 0° latitude, has a circumference of 360°, allowing it to be divided into exactly 72 5° arcs. However, the 15° North

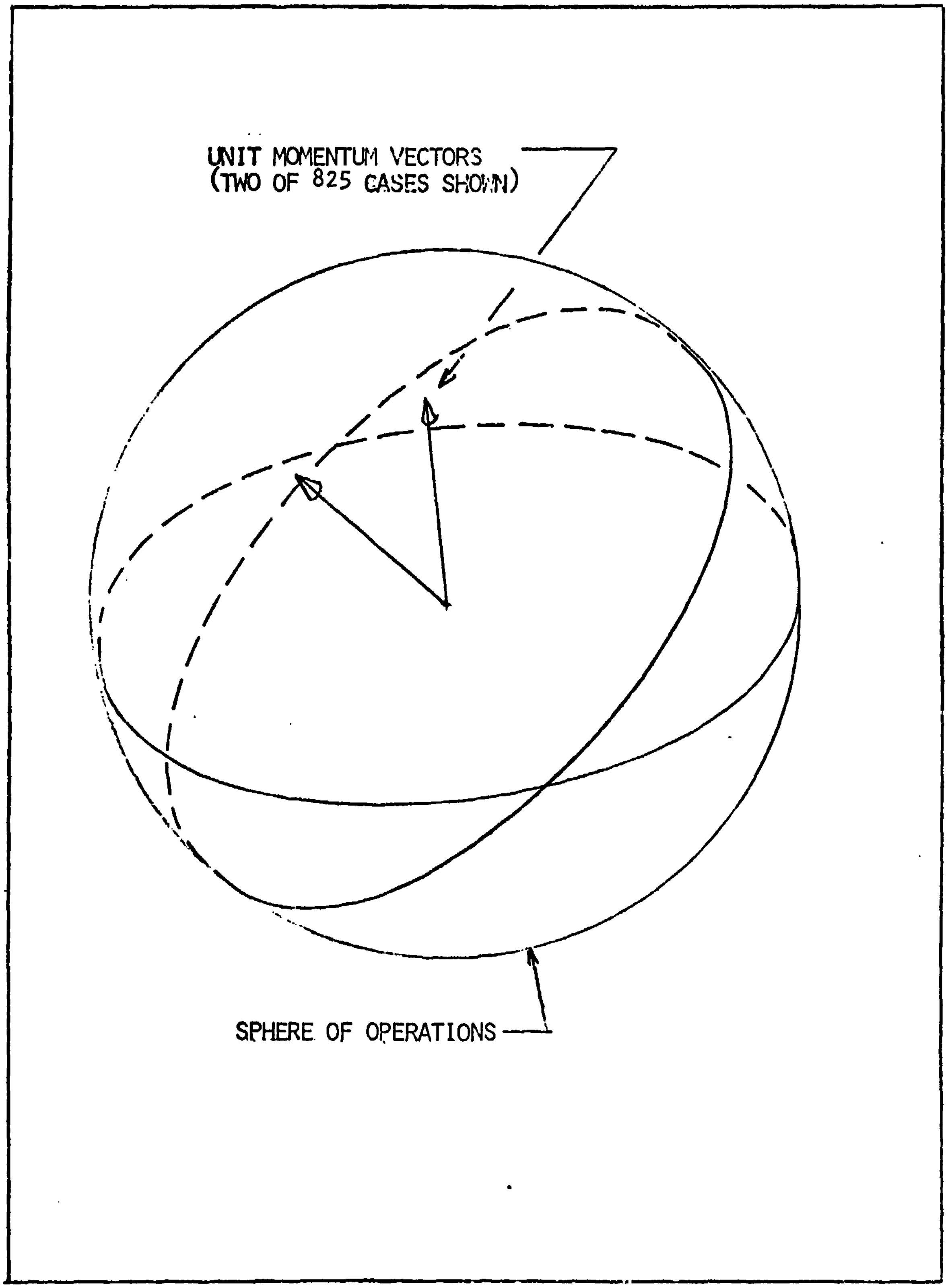


Fig 13. Space-Based Alternative Orbits

latitude circumference is only 347.7333^{0} in circumference, when measured in terms of the circumferential distance a 1 arc degree would describe at the equator (great circle). Therefore, only 69.5467 5^{0} arcs could be transcribed around its circumference. However, if we move South to the 13.5362^{0} latitude, exactly 70 5^{0} arcs can be defined around the circumference.

This technique of finding the "nearest latitude" was repeated over all latitudes from 5^{0} North to the northern pole of the sphere. The results are shown in table III . The southern hemisphere is a mirror image of the northern hemisphere. Figure 11 depicts a typical sphere of operations.

TABLE III

Number of "Great Circle Five Degree Arcs"

for North Latitudes of a Sphere of Operations

True Latitude	Nearest Latitude	Number of 5^{0} Arcs
0^{0}	0^{0}	72
5^{0}	5^{0}	71.72602
10^{0}	9.5603	71
15^{0}	13.5362	70
20^{0}	19.1881	68
25^{0}	25.4744	65
30^{0}	30.5584	62
35^{0}	34.9708	59
40^{0}	40.1918	55
45^{0}	44.9005	51
50^{0}	50.2910	46

True Latitude	Nearest Latitude	Number of 5^{o} Arcs
55^{o}	55.2885	41
60^{o}	60.0000	36
65^{o}	65.3757	30
70^{o}	69.6825	25
75^{o}	74.6991	19
80^{o}	80.4059	12
85^{o}	85.2198	6
90^{o}	90.0000	(1 PT)

Submodel SPHERE calculates the cartesian coordinates of all of these points and stores them for use later in the model (fig 14). See Appendix C for a FORTRAN listing of this submodel.

Submodel TARGET

TARGET uses the orbital parameters of the satellite targets selected to randomly place them into their orbits. The only "phase relationships allowed in this first HELBASE version is between the sub-synchronous and synchronous targets.

The algorithm used is the "mean anomaly to eccentric anomaly to true anomaly technique" (Ref 5:182-185). A mean anomaly is randomly drawn from a uniform (0, 2π) distribution. The mean anomaly M is related to the eccentric anomaly E by:

$$M = E - e\sin E$$

where e is the eccentricity of the orbit. A root solution numerical technique is used to find the zero value (E_o) of:

f (E) - E - esinE - M,

where e and M are known. The technique used (ZBRENT, International

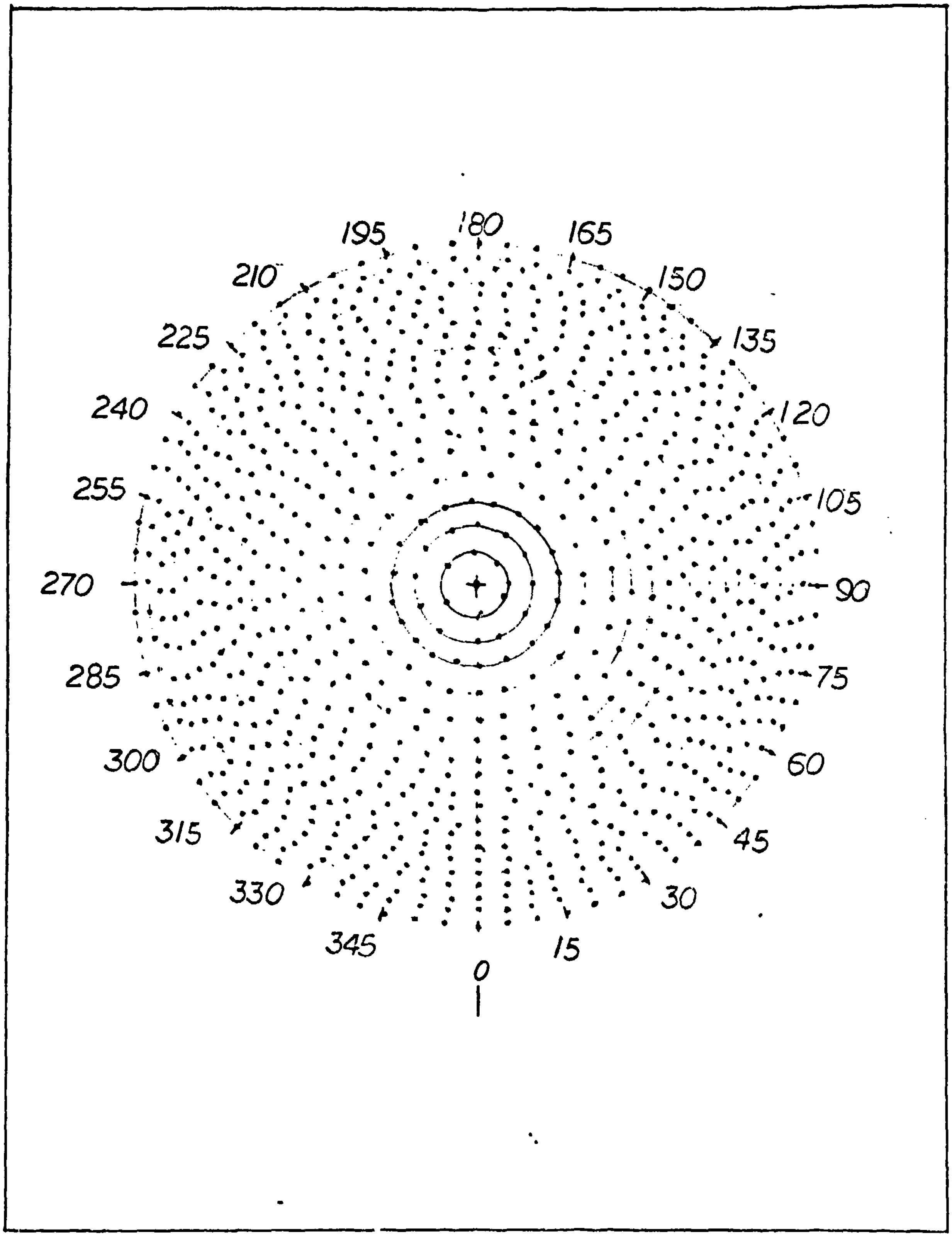


Fig 14. Points on a Sphere of Operations

Mathematical and Statistical Libraries), requires that E values (initial guesses) be input such that their functional values (F (E)) have different algebraic signs. The simple algorithm of making the first guess E_1 = M - 2e and the second guess E_2 = M + 2e guarantees that $f(E_1) < 0$ and $f(E_2) > 0$.

The E_0 value is then used to calculate the true anomaly by:

$$\nu = \cos^{-1}\left(\frac{e - \cos E_0}{e \cos E_0 - 1}\right)$$

Note that the root solution procedure is unnecessary when e is zero, since in this case the mean, eccentric, and true anomalies are the same.

<u>Sighting Efficiency and Submodel SIGHT</u>

"Sighting Efficiency" is not only the basis of submodel SIGHT, it is the fundamental attribute upon which submodel OPTIMIZE selects the "most efficient" weapons to construct the final weapon system.

Several attributes were considered before the decision was made to employ "sighting efficiency." Each of the alternatives had drawbacks, but the attribute selected seems to encompass the essence of "most efficient" and has validity for a majority of possible model users.

<u>Development of Sighting Efficiency</u>. The objective under consideration here is "to place the next weapon in the most efficient position." Efficiency is defined in terms of determining the weapon system composed of the least number of weapons needed to accomplish the mission. A definition refinement process was used in determining the attribute which could in a reasonable way measure the attainment of this objective.

The efficiency attribute was to be defined first for a point (1 of the 1650) on the sphere of operations, and then extended to measure the efficiency of the weapon path (latitudinal circle or orbit).

The first attribute considered was simply the <u>average percentage</u> of the total target system which could be "sighted" at any point in time. The approach was to randomly distribute the satellites in the target system, and then to determine whether each of them could be "seen" from each point on the sphere of operations. A "sighting" in this case was defined as 1) satisfaction of non-interference of the earth with the shot, 2) a check of the maximum weapon range (a function of pointing accuracy and 3) a check of the maximum irradiation time allowed against what was required to negate the target. A binary coding system was to be used to record the satisfaction of these checks. Non-interference with the earth, less than maximum range and less than maximum irradiation time would be coded as a "1", and violation of any of these three constraints would be coded as a "Ø". Adding and then averaging these values over many random draws of the targets would yield the desired average percentage. For instance, the sighting of 5, 6, 12 and 2 targets out of 15 over 4 stochastic draws of the targets would yield a value of .4167 for that point on a specific sphere of operations. That is, an average of about 42% of the targets could be seen from that point at a given time.

The impact of the weapons <u>already placed</u> into the weapon system by the submodel OPTIMIZE was represented by discounting any "sighting" which could also be "sighted" by any of the weapons already placed. This was intended to bias the placement of the next weapon away from the sphere of operations areas already "covered" by placed weapons.

This attribute was soon recognized to be too simple and incomplete. It was recognized that this measurement paid no attention to the irradiation time required to negate the target (other than an upper limit check). This meant that a negation which would take 15 seconds from a range of 10,000 KM and a negation of 2 seconds at 1000 KM would both receive a value of "1". Therefore, the submodel OPTIMIZE would as likely pick a point characterized by longer irradiation times as one characterized by shorter times. So this first attribute attempt violated the "completeness" property, (Ref 10:50) in that it proved inadequate to measure the degree to which the objective was obtained. It was apparent that "most efficient" points, and then weapon paths, should be measured by something more than a binary (0, 1) "no sighting" or "sighting" criteria.

The second attempt at the definition of an attribute by which to measure the "most efficient" point on the sphere of operations therefore included the irradiation time required for a specific weapon placed at that point to negate a target. This was accomplished by dividing the previous binary "1" by the "irradiation time required" to negate the target. For example, a sighting of 2 out of 10 targets at negation times of 10 seconds apiece would yield a value of $\frac{1}{10} + \frac{1}{10} = .20$. Also, the sighting of 1 target out of 10 at a negation time of 5 seconds would yield $\frac{1}{5} = .20$. These events are therefore considered to be of equal value. The definition of a "sighting" remained the same as before: line-of-sight interference with the earth, maximum range, and maximum irradiation time allowed.

At this point it was noted that discounting <u>all</u> sightings of targets which could also be seen by any of the weapons already placed tended to overcompensate for the weapons placed. No accounting for the <u>capability</u> of the placed weapon to <u>actually</u> negate the targets it could "see" was being made. It was feasible that a placed weapon with only one operating cycle in its design lifetime could prohibit the allocation of any other weapons to its portion of the sphere of operations.

Allowing one discounting of a sighting by a placed weapon seemed too conservative, so the manner by which the effect of the weapons already placed could be represented became a problem. The matter was finally resolved by taking as the initial target system (to be looked at by all points over all spheres of operations) the targets which re-mained after a BATTLE.

The submodel BATTLE was to be run for the input mission negation time. Any targets left after this time would be looked at, and the "sightings" scored by one divided by the "irradiation time required" as before. The placement of the next weapon would therefore be made contingent upon the effect of all weapons previously placed.

An additional benefit occurred when it was decided to take the remaining target set after reaching the user input mission negation time in a BATTLE. Additional information, in the forms of total weapon operating cycles (or total irradiation time allowed), and weapon re-cycle time were implicitly included in the effect the "already placed" weapons would have on the target system.

Submodel SIGHT. The submodel SIGHT was designed specifically to provide a value of sighting efficiency, for a "one-on-one" look for a point on a sphere of operations at a target. (see fig 7). If a line-of-sight check did not prohibit a "shot" (see figures 15,16,&17),then checks would be made for exceeding the maximum allowable irradiation time for a weapon operation, and the maximum distance allowable (function of pointing accuracy).

Calculation examples are shown in the section which discusses the submodel "SIDEN." See Appendix C for a listing of SIGHT in Fortran.

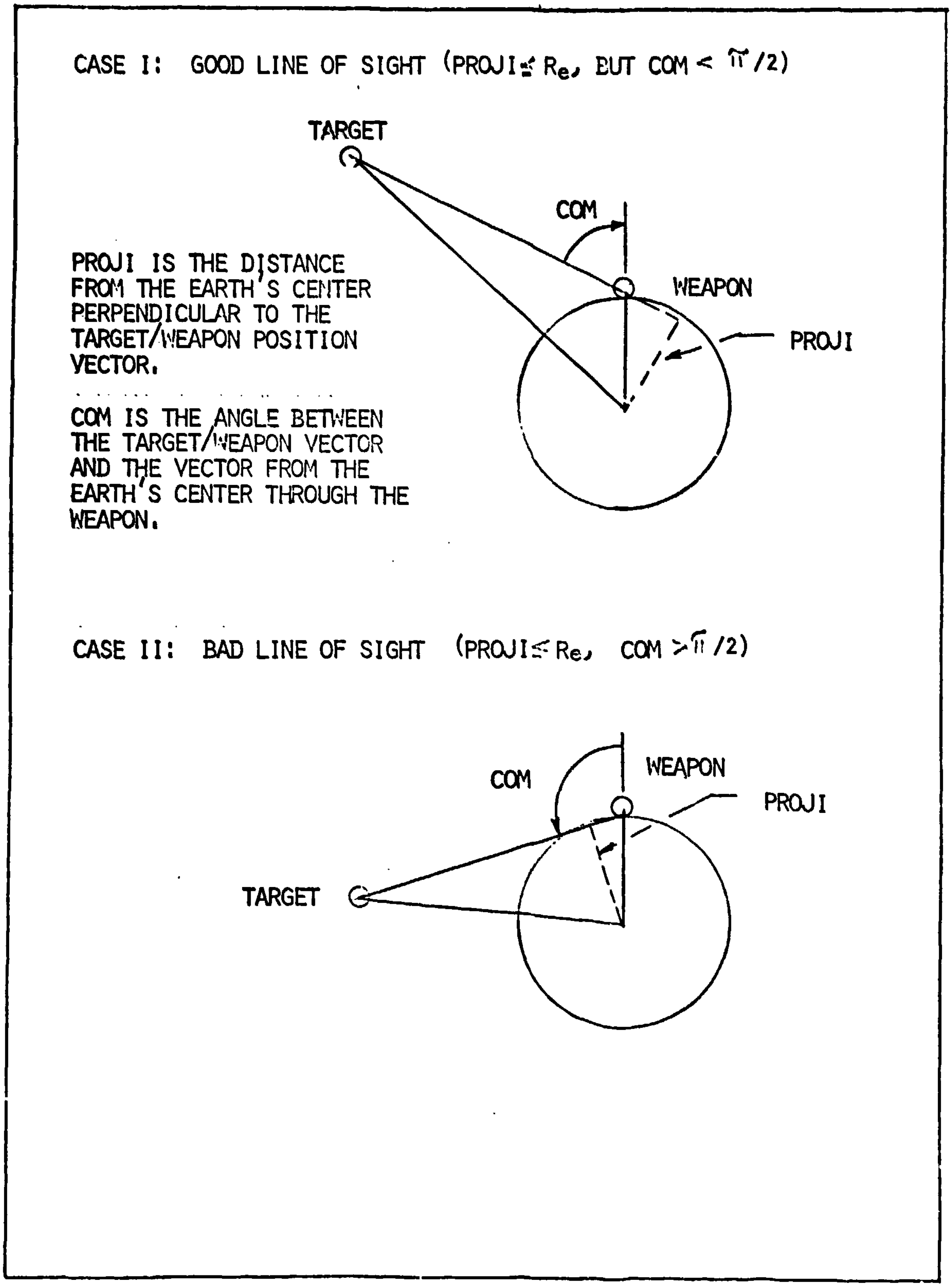
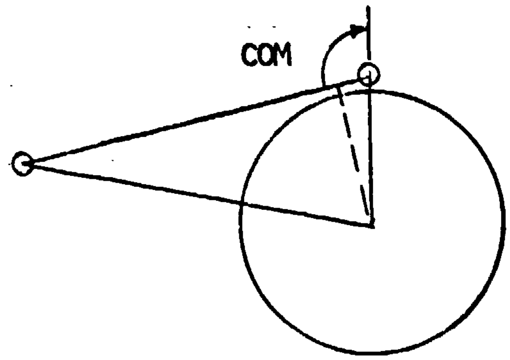


Fig 15. Line of Sight, Ground-Based Case

CASE II: BAD LINE OF SIGHT $(PROJI < R_e)$



CASE I: GOOD LINE OF SIGHT $(PROJI < R_e$, BUT $COM < \pi/2)$

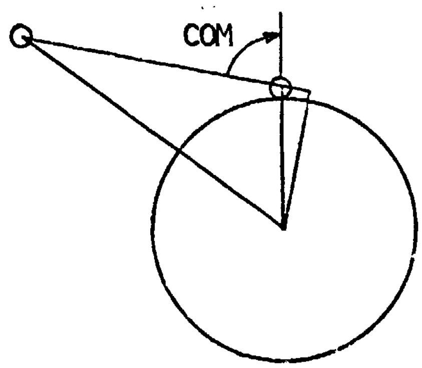


Fig 16. Line of Sight, Air-Based Case

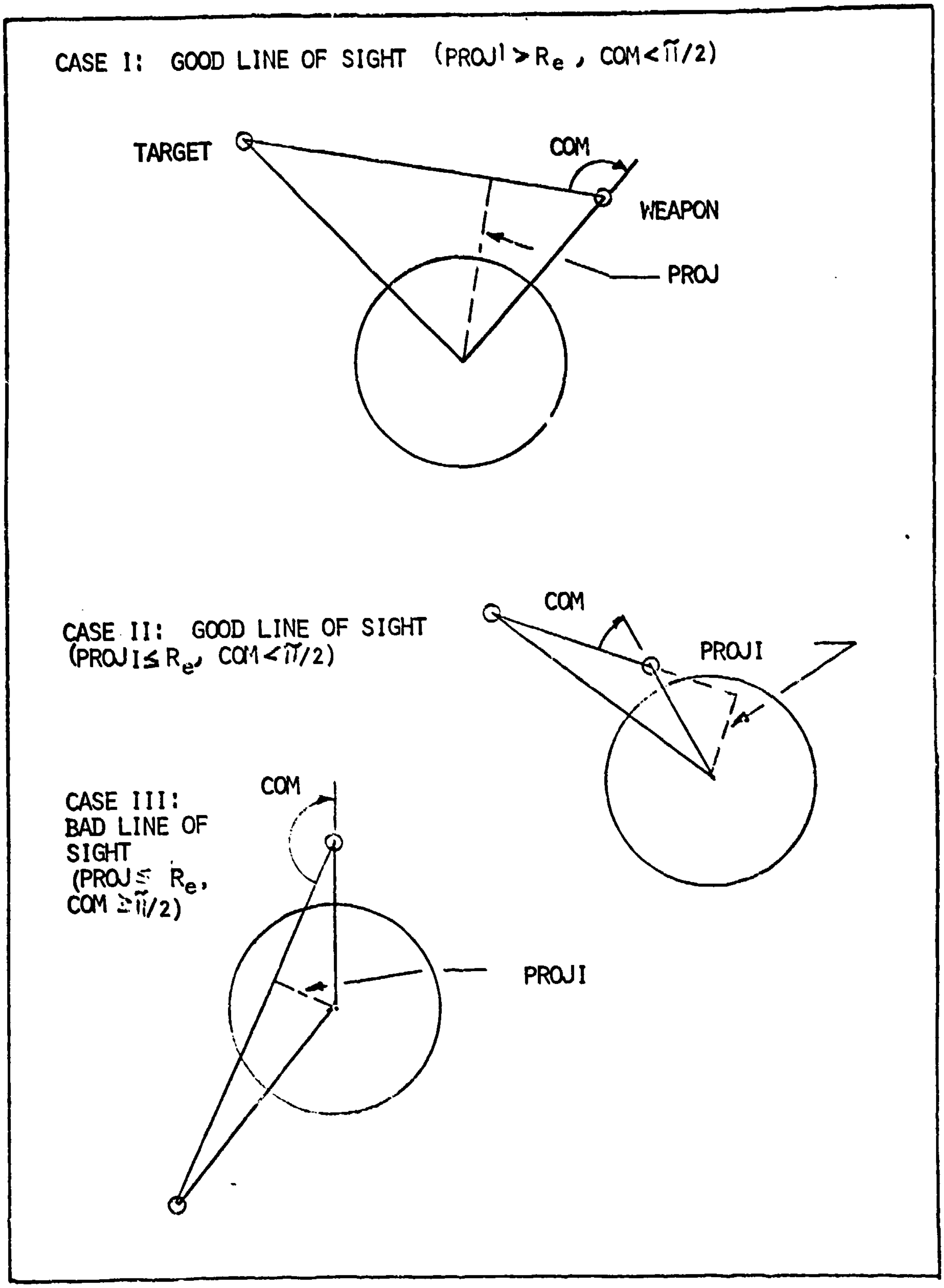


Fig 17. Line of Sight, Space-Based Case

Submodel SIDEN. The function of SIDEN is to collect the data necessary and then to calculate the "target sighting efficiency" for each point in each sphere of operations.

For one point on a sphere of operations looking at one target, we have

$S = \frac{1}{t}$, where

S = Sighting efficiency, and

t = Irradiation time required to negate the target.

If we extend this concept to n targets (in the target system), where $k = 1, 2, \ldots, n$, then

$$\bar{S} = \sum_{k=1}^{n} S_k = \sum_{k=1}^{n} 1/t_k$$

where t_k is the irradiation time required to negate the k th target, and $\bar{s}$ is the average of S_k over all n targets.

Extending the "sighting efficiency" concept to multiple stochastic draws of the targets ($j = 1, 2, \ldots, m$) for m iterations, we have

$$EFF = \sum_{j=1}^{m} \frac{1}{m} \left[\sum_{k=1}^{n} 1/t_{jk} \right]$$ where

EFF = Average sighting efficiency of the point over m stochastic draws of n targets.

t_{jk} = Negation time required for the jth drawing of the kth target.

This average sighting efficiency for a point on the sphere of operations is extended to include the path average sighting efficiency in the submodel OPTIMIZE (See Appendix D).

Submodel PROP

This section investigates the basis and development of the submodel PROP (propagation) whose purpose is to translate beam intensity at the source to beam intensity at the target.

The only effects modeled in this first-order model (see Chapter II, Limitations) are beam spreading (for all basing modes), and beam absorption (for air-or ground-based weapons). Beam spreading does <u>not</u> include thermal blooming, and beam absorption does not include aerosols or particulates.

<u>Beam Absorption</u>. Absorption of the laser beam during its transition through the atmosphere is modeled on a standard atmosphere. The fundamental formulation is an extension of Beer's law to a non-homogeneous medium.

For an aircraft-based weapon firing vertically up through the atmosphere, the intensity at the target is given by (Ref17):

$$I_{TA} = I_o \, e^{\int_{h-y}^{h} N\sigma e^{-x/8.5} dx}$$

where

I_{TA} = Beam intensity at the target,

I_o = beam intensity at the weapon,

h = Weapon height from the surface of the earth,

N = Molecular density of the air,

σ = Absorption coefficient,

y = Vertical height from weapon to target, and

x = Distance along beam from weapon to target.

(See figure 18).

If the effect of shooting at an angle (θ) from the local vertical is included in our beam absorption, we have

$$I_{TA} = I_o \, e^{\frac{N\sigma}{\cos\theta} \int_{h-y}^{y} e^{-x/8.5} dx}$$

Note that for a ground-based weapon, h - y = 0, so that

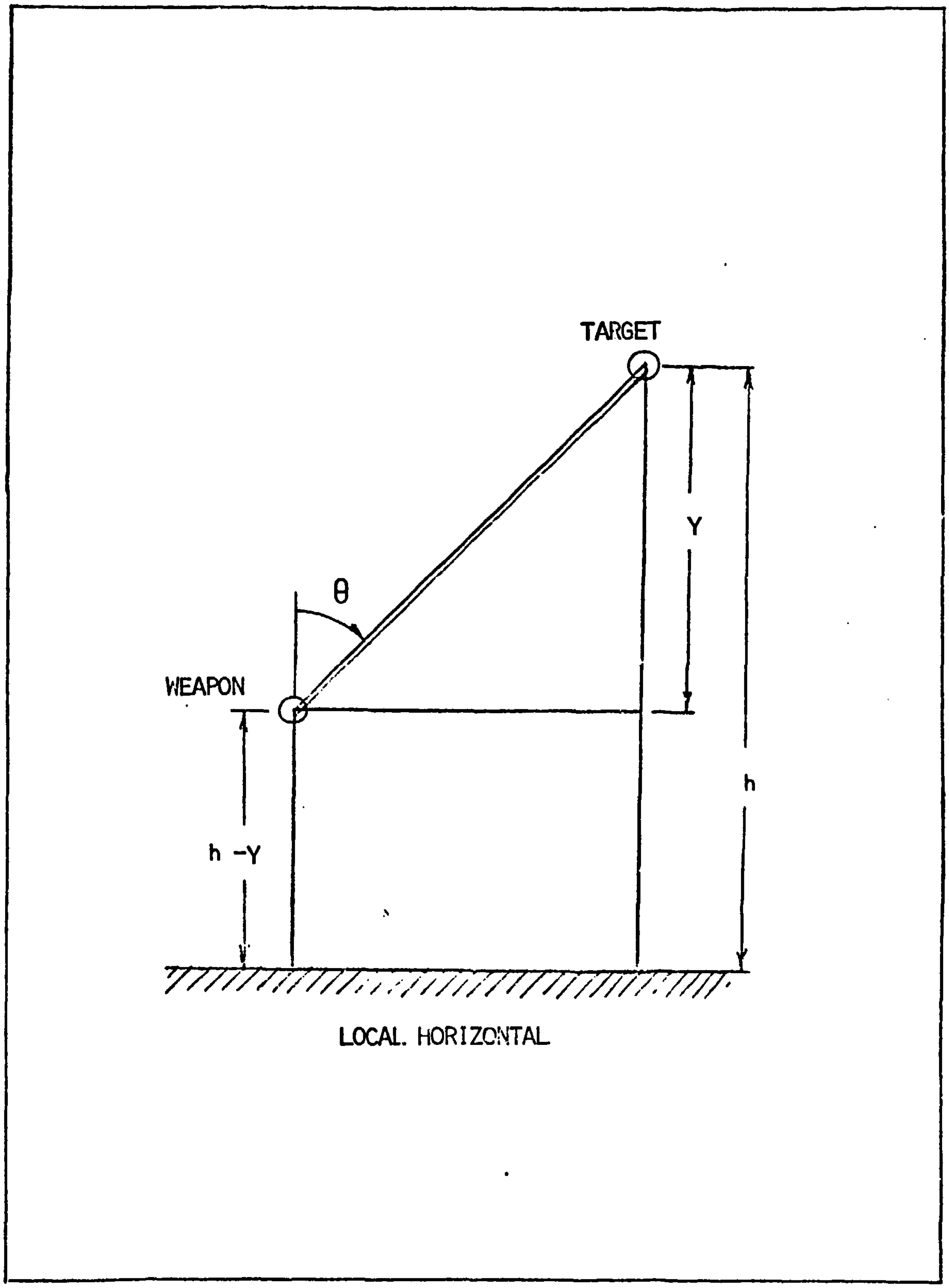


Fig 18. Beam Absorption Geometry

$$I_{TA} = I_o\, e^{\frac{N\sigma}{\cos\theta}\int_0^h e^{-x/8.5}\,dx}$$

(Ground-Based Weapon)

A simple approximation can be made to avoid wasting computer time on numerical integrations (PROP may be called on the order of one million times during a run of HELBASE). A simple sensitivity analysis showed that very little difference in the value of I_t (less than .0001%) is found if the upper limit of integration is set at 200 KM. Therefore, we have

$$I_{TA} = I_o\, e^{\frac{N\sigma}{\cos\theta}\int_{h-\gamma}^{200} e^{-x/8.5}\,dx}$$

or approximately

$$I_{TA} = I_o\, e^{\frac{-8.5\, N\sigma\, e^{-(h-\gamma)/(8.5)}}{\cos\theta}}$$

Beam Spreading. An independent phenomenon associated with laser beam transmission over long distances is beam divergence, or beam spreading. The fundamental formulation of the beam divergence is based upon a collimated (non-focused) beam of waist size w_0 at the source. A collimated beam will spread proportionately to its wavelength and inversely proportionately to its waist size (Ref 7; 6:17). The "waist size" (a gaussian beam is assumed) can be thought of as the radius from beam center to a point at which the irradiance is $1/e^2$ of that at beam center (Ref 6:247). The waist size of the spreading beam can ("far" from the source) be expressed as:

$$\omega_z = \omega_0 \left[1 + \left(\frac{\lambda z}{\pi \omega_0^2} \right)^2 \right]^{1/2}$$

where

ω_0 = Waist size at the source,

ω_z = Waist size at target,

λ = Beam wavelength, and

z = Distance from weapon to target (Ref 7).

Simple geometry provides the relationship for the reduction in beam intensity resulting from beam spreading

(I_{TS} = Intensity at target reduced by beam spreading)

$$I_{TS} = I_0 \left(\frac{\omega_0}{\omega_T} \right)^2$$

<u>Combined Beam Spreading and Absorption</u>. Combining the results of the last two sections can be expressed as:

$$I_T = I_{TA} \left(\frac{\omega_0}{\omega_T} \right)^2$$

where I_0 has been replaced by I_{TA}, the attenuated beam intensity at the target. This relationship expands to

$$I_T = I_0 \, e^{\frac{-8.5 N \sigma}{\cos \theta} e^{-(h-y)/8.5}} \left(\frac{\omega_0}{\omega_T} \right)^2$$

This expression of the final beam intensity at the target is appropo for ground and air-based weapons. For space-based weapons, the simple beam expansion formula is used.

<u>Submodel EFFECT</u>.

The submodel EFFECT is designed to "use" data of the general type found in the Foreign Technology Division/Lockheed Missile and Space

Company's "Project ESS" analyses. For a look at representative data from these studies, see Appendix A.

The data can be reduced (Appendix A) to a quadratic expression of the form

$$at^2 + bt + \left(c - \sqrt{\frac{d}{\lambda_j}}\ I_t\right) = 0$$

where

a, b, c, d, are quadratic curve fitting and data constants based on the data,

t = The negation time (irradiation time) required to negate the target),

λ_j = Wavelength of the beam under consideration, and

I_t = Beam intensity at the target.

This relation can be solved for the negation time, which is the output of EFFECT:

$$t = \frac{-b + \left[b^2 - 4a\left(c - \sqrt{d/\lambda_j}\ I_t\right)\right]^{1/2}}{2a}$$

This simple algorithm may be inspected in Appendix C.

Submodel OPTIMIZE

The most important function of the submodel OPTIMIZE is to identify the single weapon path (latitudinal circle or orbit) which is the "most efficient," because onto this path the next weapon allocated will be placed.

Various techniques were investigated, some of which may be the basis of the future for model expansion (see Appendix B). The methodology finally selected involves a straightforward check of all the possible paths, with selection of the maximum as the "most efficient."

For each ground - or air-based weapon, a "path sighting efficiency" around each latitude across the sphere of operations (in 5° intervals) is calculated. This amounts to 37 possible paths for each weapon. For each space-based weapon, there are 825 possible orbits. These orbits are defined by the direction of the angular momentum vectors (see fig 11) going through the upper hemisphere of points defining a sphere of operations.

Calculating a "path sighting efficiency" for each of these 825 orbits meant finding the locus of points on the sphere of operations which most closely approximated the orbital path. However, once the sequence of points constituting each orbital path were identified, they could be used for all space-based spheres of operation. The idea was to find the 36 points which would define each of the 825 orbits, and to store this data until needed (permanent storage). For this purpose, a subroutine called ORB was developed (see Appendix C).

<u>Subroutine ORB</u>. The subroutine ORB was needed only to define the 36 points on each of the 825 orbits. A fundamental part of this subroutine is the capability to rotate the three-dimensional cartesian coordinate axes. A brief development of these axes rotations is presented here prior to looking at the methodology of determining the 36 points of each orbit.

Figure 19 shows a typical vector in both the spherical and cartesian coordinate systems.

Transformation of spherical coordinates to cartesian coordinates is a one-to-one transformation, and is simply

$$x = \rho \sin\theta \cos\phi$$
$$y = \rho \sin\theta \sin\phi$$
$$z = \rho \cos\theta$$

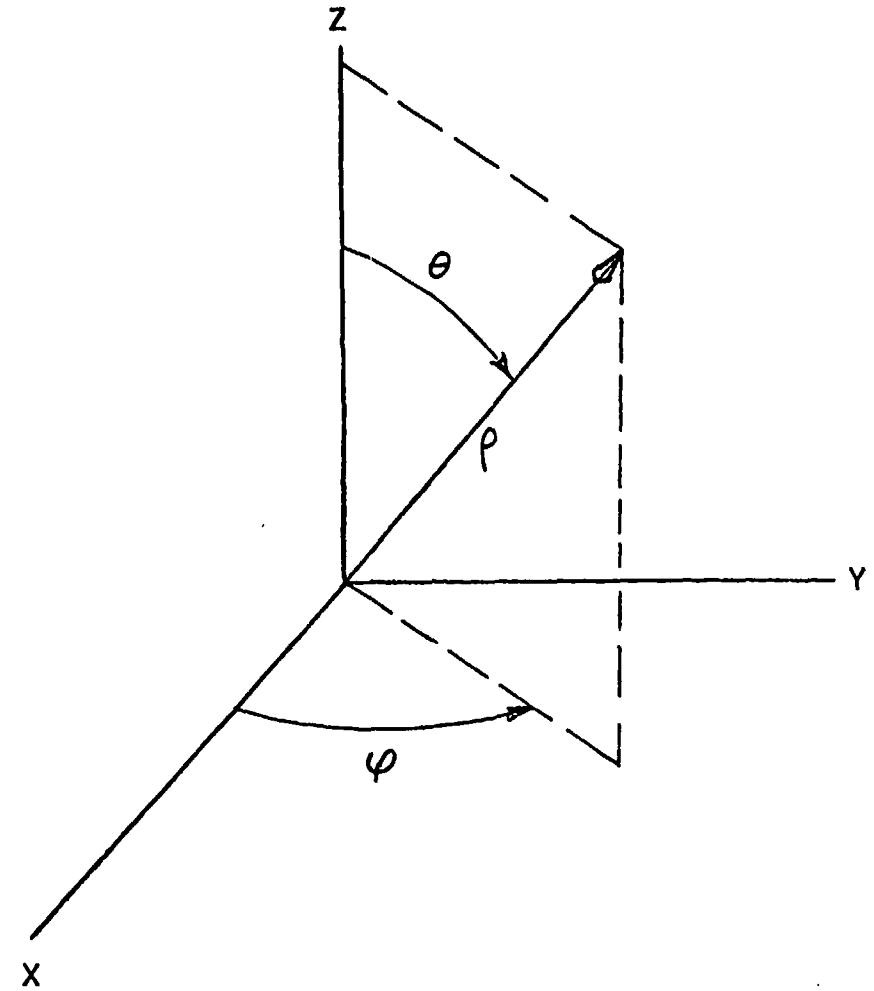


Fig 19. Spherical and Cartesian Coordinate Systems

Transformation of cartesian coordinates to spherical coordinates is not a one-to-one transformation. We may say that

$$\rho = \sqrt{x^2 + y^2 + z^2} \qquad \theta = \sin^{-1}\left(\frac{x^2+y^2}{x^2+y^2+z^2}\right)^{1/2}$$

$$\phi = \tan^{-1}\left(\frac{y}{x}\right)$$

, and

where the following algebraic sign combinations exist:

$$(x-, y-, z+)^{*}\,(x-, y-, z-)^{*}\,(x+, y+, z+)\,(x+, y+, z-)\,(x+, y-, z+)\,(x+, y-, z-)$$

For the rest of the octants, we may say that $\phi = \cos^{-1}(x/\rho\sin\theta)$

where, the following algebraic sign combinations exist:

$$(x^+, y^+, z^+)(x^+, y^+, z^-)(x^-, y^+, z^+)(x^-, y^+, z^-)$$

*Note: For these algebraic sign combinations, $\phi = -\sin^{-1}(y/\rho\sin\theta)$

To rotate the cartesian coordinate reference system through an angle Ø about the Z axis, we take (Ref A: 77-80)

$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix}$$

To rotate this reference system through an angle $(\theta - \pi/2)$ about the y axis, we take

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = \begin{bmatrix} \cos(\theta-\pi/2) & 0 & -\sin(\theta-\pi/2) \\ 0 & 1 & 0 \\ \sin(\theta-\pi/2) & 0 & \cos(\theta-\pi/2) \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix}$$

Therefore to rotate the reference system through an angle ϕ about the z axis, and then through an angle $(\theta - \pi/2)$ about the <u>rotated</u> y axis, we can say that

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = \begin{bmatrix} \cos(\theta-\pi/2) & 0 & -\sin(\theta-\pi/2) \\ 0 & 1 & 0 \\ \sin(\theta-\pi/2) & 0 & \cos(\theta-\pi/2) \end{bmatrix} \begin{bmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix}$$

or

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = \begin{bmatrix} \cos(\theta-\pi/2)(\cos\phi) & \cos(\theta-\pi/2)(\sin\phi) & -\sin(\theta-\pi/2) \\ -\sin\phi & \cos\phi & 0 \\ \sin(\theta-\pi/2)(\cos\phi) & \sin(\theta-\pi/2)(\sin\phi) & \cos(\theta-\pi/2) \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix}$$

Similarly, a rotation matrix was developed to rotate a given reference system backward through $(\pi/2 - \theta)$ about the y axis, and then through $(-\phi)$ about the rotated z axis

$$\begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} = \begin{bmatrix} \cos\phi\cos(\pi/2-\theta) & -\sin\phi & -\cos\phi\sin(\pi/2-\theta) \\ \sin\phi\cos(\pi/2-\theta) & \cos\phi & -\sin\phi\sin(\pi/2-\theta) \\ \sin(\pi/2-\theta) & 0 & \cos(\pi/2-\theta) \end{bmatrix} \begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix}$$

We are now ready to investigate the methodology used to determine the points used in each of the orbits. The methodology is that employed in subroutine ORB (see Appendix C). Notation used in this section is as follows:

Cartesian coordinates: X_o^1 — Point number (superscript); Reference system (subscript)

Spherical coordinates: ϕ_o^1 — Point number (superscript); Reference system (subscript)

Axes:

X_o Original x axis

Z_R Rotated Z axis.

We start with the cartesian and spherical coordinates of a point on the sphere of operations which represents the unit angular momentum vector. The superscript M is used on the coordinates to designate a unit momentum vector as opposed to a point number on an orbit (see fig. 20).

The first step is to rotate the original (Xo, Yo, Zo reference system through the angle ϕ_o^M about the Z_o axis, and then through the angle $(\Theta_o^M - \pi/2)$ about the Y_R axis via the following matrix:

$$\begin{bmatrix} X_c^M \\ Y_R^M \\ Z_c^M \end{bmatrix} = \begin{bmatrix} \cos(\Theta_o^M - \pi/2)\cos(\phi_o^M) & \cos(\Theta_o^M - \pi/2)\sin(\phi_o^M) & -\sin(\Theta_o^M - \pi/2) \\ -\sin(\phi_o^M) & \cos(\phi_o^M) & 0 \\ \sin(\Theta_o^M - \pi/2)\cos(\phi_o^M) & \sin(\Theta_o^M - \pi/2)\sin(\phi_o^M) & \cos(\Theta_o^M - \pi/2) \end{bmatrix} \begin{bmatrix} X_o^M \\ Y_o^M \\ Z_o^M \end{bmatrix}$$

Coordinates of the momentum vector in the rotated reference frame.

Coordinates of the momentum vector in the original reference frame.

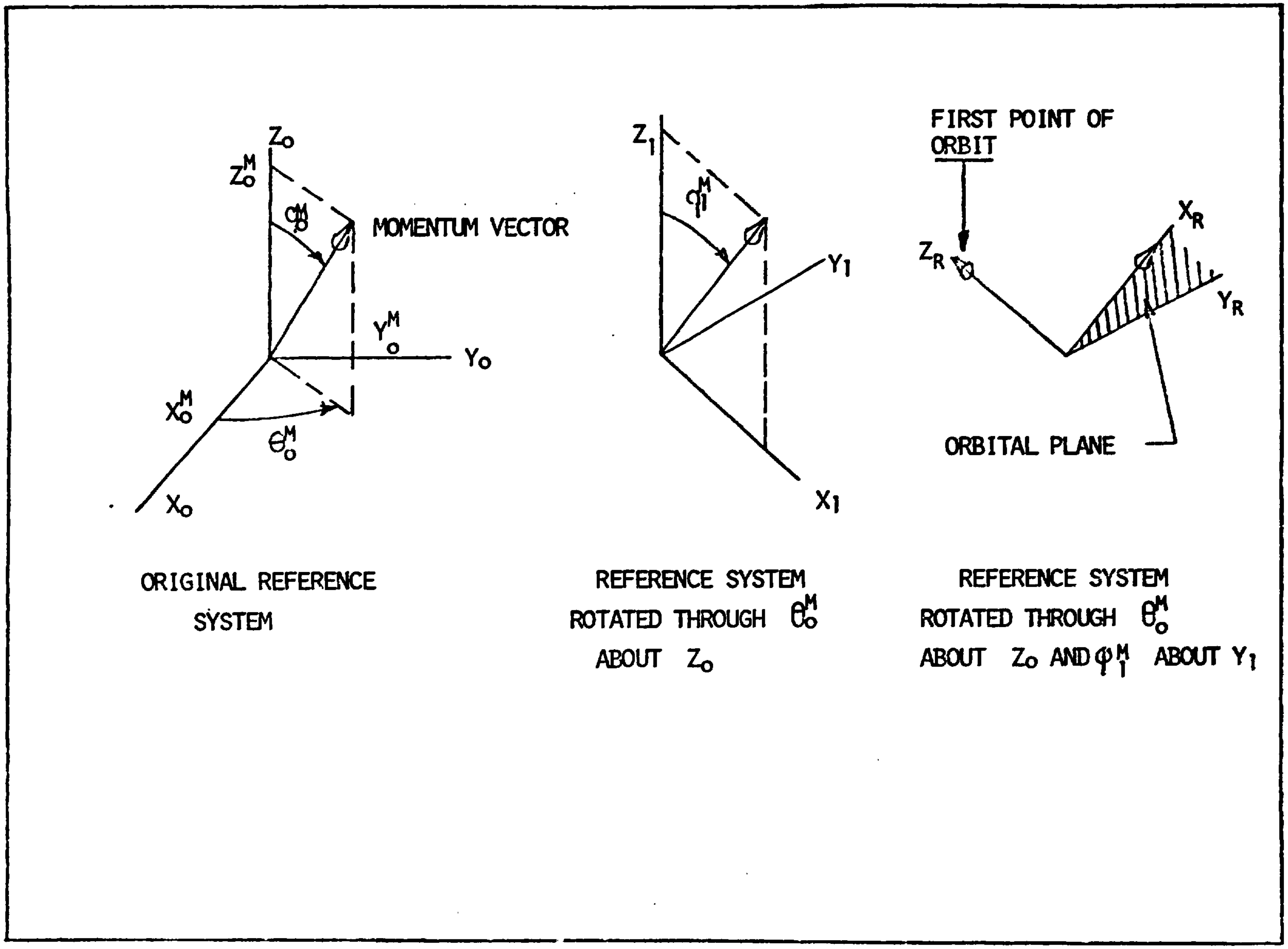


Fig 20. ORB Axis Rotations

These rotations place the X_R axis along the momentum vector, and the Z_R axis through the first point of the orbit.

The coordinates of this first point on the orbit are ρ_R, $\varphi'_R = 0$, $\theta'_R = \pi/2$.

The task now is to express the coordinates of this point in terms of the original reference system (Xo^1, Y_0^1, Z_0^1). We therefore must rotate the coordinates of the first point backward through $-(\theta_0^M - \pi/2)$ about the Y_R axis, and then through $(-\phi_0^M)$ about the Z_0 axis.

$$\begin{bmatrix} x'_0 \\ y'_0 \\ z'_0 \end{bmatrix} = \begin{bmatrix} \cos(\varphi_0^M)\cos(\pi/2 - \theta_0^M) & -\sin(\varphi_0^M) & -\cos(\varphi_0^M)\sin(\pi/2 - \theta_0^M) \\ \sin(\varphi_0^M)\cos(\pi/2 - \theta_0^M) & \cos(\varphi_0^M) & -\sin(\varphi_0^M)\sin(\pi/2 - \theta_0^M) \\ \sin(\pi/2 - \theta_0^M) & 0 & \cos(\pi/2 - \theta_0^M) \end{bmatrix} \begin{bmatrix} x'_R \\ y'_R \\ z'_R \end{bmatrix}$$

Similarly, to obtain the coordinates of the jth point of the ith orbit, add 5^0 to the θ of the $(j - 1)$ st point, and solve for the cartesian coordinates in the rotated reference frame. We know that

$$\rho_R^j = \rho = \text{constant},$$
$$\varphi_R^j = \pi/2 = \text{constant, and}$$
$$\theta_R^j = \theta_R^{j-1} + 5^\circ$$

So

$$x_R^j = \rho\cos(\varphi_R^j)\sin(\theta_R^j) = 0$$
$$y_R^j = \rho\sin(\varphi_R^j)\sin(\theta_R^j) = \rho\sin(\theta_R^j)$$
$$z_R^j = \rho\cos(\theta_R^j)$$

We can then solve for the $(\varphi_0^j, \theta_0^j, \rho)$ of the original reference system.

The last step in the process of defining the points which describes a given orbit over the surface of a sphere of operations is to find the closest point to our above precisely defined orbital point. The algorithm for accomplishing this is shown in Appendix C.

Submodel BATTLE

The purpose of the submodel BATTLE is to allow the placed weapons to fire against the targets over the mission negation time, under the constraints imposed by the user. Fig10in Chapter II shows the functional flow of BATTLE, and the Fortran subroutine is reproduced in Appendix C.

The functional description in Chapter II, Table I , and Appendix C describe the various combinations of tactics available to the user. This section concentrates on two modeling aspects of this many-on-many engagement submodel.

The first matter to be investigated is the selection of the "proper" Δt for use in advancing the BATTLE clock. Items to be considered in the selection of a Δt are: 1) the angular travel of the satellite which has the highest angular velocity at perigee, 2) the mission negation time, 3) the minimum of all weapon recovery times, and 4) computational cost.

BATTLE Δt. The amount of an orbit covered by the targets and the orbital weapons during a Δt should heuristically be kept small enough to allow target acquisition by weapons which could "sight" the target during its perigee passage. The probable target types with the highest eccentricity and the longest semi-major axis will have these approximate characteristics: e = .90 and

a = 9400 KM.

From the expression for the incremental time necessary to traverse an incremental portion of the true anomaly (Ref 5:31),

$$dt = (r^2/h)\, d\nu$$

where r = Instantaneous radius,

h = Angular momentum, and

ν = True anomaly,

we can say (for "small" Δt and $\Delta\nu$), that

$$\Delta t = \frac{r^2}{h}\Delta\nu .$$

From

$$h = \left[a(1-e^2)\mu\right]^{1/2}$$

where

$$\mu = 3.986 \times 10^5\ KM^3/sec^2,\ \text{and}\ r_p = a(1-e)$$

we can say that (for satellites near perigee),

$$\Delta t \approx \frac{\left[a(1-e)\right]^2\Delta\nu}{\left[a\mu(1-e^2)\right]^{1/2}} = \frac{a^{3/2}(1-e)^2\Delta\nu}{\left[\mu(1-e^2)\right]^{1/2}}$$

So for the case of $e = .91$,

$a = 9356.96$ KM, and $\Delta\nu = 15^0$ (.2618 radians,

$$\Delta t = 7.33 \text{ seconds.}$$

So, we are considering a lower bound for BATTLE Δt of about 7 seconds. The second item to be considered is the user defined mission negation time.

A short mission negation time, on the order of minutes as opposed to hours, may create irregularities in functions of BATTLE if the BATTLE Δt clock advancement increment becomes a "large" portion of the mission negation time. For example, a mission negation time of 1 hour, a BATTLE Δt of 5 minutes, and an average target irradition time of 10 seconds would allow only 20 opportunities for the weapons to fire against the targets. A shorter Δt would allow more firing opportunities, and a closer approximation of realizing the full potential of the weapon system. So we must decrease the BATTLE Δt or institute some lower limit on the user input mission negation time. For example, mission negation time divided by Δt should not be too much less than the maximum firing time allowed.

Weapon recycle time is a factor in that a BATTLE Δt which is much larger than the shortest recovery time would allow the creation of inefficiencies in weapon employment which are purely the result of the modeling process.

A pervasive item which is a real limit on all simulations is the computer time (cost) required to accomplish the simulation. A BATTLE Δt which is shorter than that required by the above three items wastes computer processing time. This constraint then would have us push the BATTLE Δt to as large a value as possible.

Reviewing the constraints on the BATTLE Δt, we have lower bounds formed by: 1) the angular travel of the "fastest" satellite during the Δt, 2) a fraction of the mission negation time, and 3) the least recovery time, and an upward pressure caused by computational cost consideration.

Mission negation times from an hour to several days are considered practical. The 7 second lower bound based on the angular distance traveled by the target satellite with the greatest eccentricity and semimajor axis can be substantially ignored with only a minor impact on BATTLE performance. Not only is the satellite near its perigee a very small portion of the orbital period, it is also a more demanding pointing and tracking problem to attack a target going through perigee for most weapon configurations. Letting the BATTLE Δt become much greater than weapon recycle time will tend to cause some inefficiencies in weapon employment when weapons which are useable (have been recycled) cannot be used because the BATTLE Δt has not been reached. However, the impact of this inefficiency is reduced by keeping the translation of the satellites along their orbital paths down to a reasonable size, so that the targets will generally still be available at the end of the BATTLE Δt.

A Δt of 5 minutes would allow a $\Delta\nu$ of about .3 radians or 17 degrees for a typical target from the target system allowed. A BATTLE Δt of much more than five minutes would introduce discontinuities in the progression of the many-on-many engagements. Unfortunately, 5 minute Δt's over a 2 day mission negation time would mean 576 iterations of the BATTLE functions.

However, a BATTLE Δt of five minutes is the original value used. A sensitivity analysis of model output to the value of the BATTLE Δt is certainly warranted (see Chapter IV).

<u>Progression of the Satellites Around Their Orbits at Each Δt.</u> Both the target satellites (through subroutine TARGET) and the weapon satellites are assigned an initial mean anomaly. The effect on the mean anomaly of a time increment Δt is given by

$\Delta M = n \, \Delta t$ (Ref A:185) where $n = \sqrt{\frac{\mu}{a^3}}$. For each satellite, then, a new mean anomaly $M_1 = M_0 + \Delta M$ can be calculated, and the root solution procedures employed in TARGET can be employed to calculate the positions of all the weapons and satellites at $t + \Delta t$.

This Chapter has investigated the underlying physical processes, methodologies, and techniques for the complicated submodels of HELBASE. The detailed information herein must be viewed in the context of Chapter I and II, which define the constraints on and functional flow of each of these submodels.

IV. Verification and Validation

The basic methodology proposed by Haley and Ghelber (Ref A) was employed in the HELBASE verification/validation process. This effort (A Methodology for Validation of Complex Multi-Variable Military Computerized Models) is well based in contemporary thought concerning the verification and validation of military simulation models, and draws on the work of Finge, Naylor, Schlesinger, Tytula, and others (Ref12,13,14). In this approach, model verification (assurance that the model functions as intended) is a part of the overall validation process.

The process is divided into four parts: 1) conceptual validity -- an assessment of the purpose, desired accuracy, assumptions, limitations and model structure, 2) verification -- using several contemporary techniques, 3) credibility -- a combination of face validation (expert judgment) and sensitivity analysis, and 4) confidence -- ways to help instill some degree of confidence about the model in the user or decision maker.

Conceptual Validity

Assessment by a potential user of the conceptual validity of HELBASE must be derived from Chapters I and II. The model purpose, degree of accuracy, assumptions, limitations and functional structure are described in detail in those chapters.

Verification

This part of the overall validation process is primarily concerned with the "mechanical" validity of HELBASE, and is composed of four parts: 1) a structured walk-through, 2) verification of technical physical processes, 3) simulation of predictable states, and 4) testing of stochastic events.

Structured Walk-Through. This part of verification establishes the event-path integrity of the model, and was accomplished for the applicable submodels (modules) as well as for the overall HELBASE model.

A structured walk-through to check the proper treatment of all legal variable combinations, was accomplished for the following: INPUT, TARGET, SIDEN, OPTIMIZE, and BATTLE. (See Chapters II and III for functional descriptions and the mathematical basis of each).

The treatment of the INPUT section was primarily concerned with checking the default mechanisms for weapon types, mission data, and battle management data. In all cases, the user must input a zero whenever the model default value is wanted. The following defaults were checked:

Weapon Types -- Beam waist size,
maximum firing cycles allowed,
maximum firing time per operating cycle,
recycle time,
maximum range allowed,
probability of failure, and
weapon attitude.

Mission Data -- Target type negation percentage, and target type priority.

Battle Management Data - Firing priorities, and sorting by irradiation time.

Submodel TARGET has three basic event paths which were checked. The normal path for the random selection of target locations is from a randomly selected mean anomaly to the corresponding eccentric anomaly and finally to the true anomaly. This path was checked by inspection of the output and by hand calculation of satellite position based on the random number drawn. There are two exceptions to this standard event path. First, target types two and three (subsynchronous and synchronous satellites) have mean anomalies which are related. The first satellite of the two sub-synchronous satellites is placed randomly, and the mean anomaly of the second satellite is 180^0 from that of the first satellite. Similarly, the mean anomalies of the second and third synchronous satellites are 120^0 on either side of the randomly selected mean anomaly of the first satellite. The second exception to the normal TARGET event path occurs when the target orbital eccentricity is zero, as for target types three and four. In these cases, the mean anomaly, eccentric anomaly and true anomaly are equal.

We have now investigated the event path integrity of submodels INPUT and TARGET. SIDEN, OPTIMIZE, and BATTLE remain.

Submodel SIDEN calls submodel SIGHT for "all" targets over all of the points on each sphere of operations. The italics around "all" indicate the dualevent path nature of this submodel. If SIDEN is called from sub-model OPTIMIZE, the target system selected by the user (with all selected targets present) is looked at ("sighted") by each of e 165Ø points on each of the defined spheres of operation. However, a call of SIDEN from the submodel BATTLE causes the deletion from sighting consideration of any targets which did not survive the BATTLE. In addition, the positions of the targets are randomly drawn by TARGET for a SIDEN call from OPTIMIZE and are taken as they are at the end of a BATTLE for a call from BATTLE.

The two basic event paths in the "next weapon placement" section of submodel OPTIMIZE are concerned with searching over all feasible latitudes for ground-and air-basing modes, and over all feasible orbits for the space-basing mode. The two event paths become one again when the path matrix is searched for a maximum (see Appendix C).

Event path integrity for the submodel BATTLE is a little more complex. The following list summarizes the decision points within BATTLE:

Initial target and weapon (random) positioning, or movement along paths (latitudes or orbits),

Calling of SIGHT to input values to the "battle efficiency" (BATTLE F) matrix - call SIGHT if the target has survived thus far and the weapon has not met its total operating cycle limit or is currently firing or being recycled.

Firing the weapons against the targets -- the user may have selected (in battle management data) <u>either</u> firing priorities "or" irradiation time <u>sorting", or</u> <u>both</u>, or <u>neither</u>.

Stopping rule option - BATTLE may be stopped by the clock reaching the mission negation time, or by the negation of all of the targets prior to the mission negation time.

Each of these event paths was checked several times. An aid in the verification process was a liberal use of explanatory comment cards before critical decision points (see Appendix C).

This completes the structured walk through of the HELBASE submodels. The second part of the verification process consists of a brief review of the HELBASE processes which are based on the laws of physics, and is followed by a look at predictable model output and a discussion of tests applicable to HELBASE stochastic processes.

<u>Verification of Technical Physical Processes</u>. The only submodels which reflect complex physical processes are SPHERE, TARGET, PROP, EFFECT, and SIGHT.

The phenomena underlying each of these submodels was covered in detail in Chapter III. In addition, hand calculations were compared to submodel outputs to check the proper coding of these relationships.

Simulation of Predictable States. The HELBASE model purpose of placing weapons in a "most efficient" manner in response to definition of weapon types, a target system, a mission, and tactics brings to mind several combinations of inputs for which an output weapon system could be predicted.

Looking at the weapon type input variables, several outcome states can be predicted for simple combinations of inputs. Definition of two weapon types in a space basing mode in an exactly identical manner with the exception of wavelength (and the corresponding absorption coefficient) should lead to a weapon system composed entirely of weapons of the type with the shorter wavelength. In a similar way, the following predictable states should occur when all inputs but the one indicated are held constant:

> Increasing weapon power level should decrease the total number of weapons required.
>
> Increasing the maximum number of firing cycles allowed should decrease the number of weapons required, unless the mission negation time is of the same order of magnitude as the number of operating cycles times the maximum firing time per operating cycle.
>
> Reducing the recycle time required should lead to fewer weapons needed.
>
> Increasing the maximum allowable firing range should lead to fewer weapons unless the range was already enough to reach all or most of the targets.

Combinations of certain target types with specific weapon types can be used to get predictable results. Selection of type four (synchronous orbit) targets with no other types should lead to placement of weapons at or near the equatorial latitudes and equatorial orbits. Definition of weapon types in the ground- and air-basing modes along with selection of the single target type two (subsynchronous) should lead to weapon placements along higher North latitudes.

Decreasing the target type negation percentage or increasing the target system negation time should tend to decrease the number of weapons required to meet the mission requirements. Setting one target type priority to anything other than the default value of one, while leaving other target type priorities at the default value should cause inefficiencies in weapon placement and therefore cause an increase in numbers of weapons needed.

In battle management data inputs, sorting by irradiation time should lead to the used fewer weapons than the default random target selection. Similarly, the assignment of firing priorities as opposed to acceptance of the default value should lead to the need for more weapons to meet the mission requirements. No "predictable state" checks have been made.

Testing of Stochastic Events. The only random selections in the HELBASE model occur in submodels TARGET and BATTLE, and are from the simple uniform (0, 2π) distribution. The simple nature and use of these random selection procedures does not seem to warrant goodness-of-fit tests on the random selections made.

However, there are three areas in the model where stochastic analysis seem appropriate. The first concerns the "average target system sighting efficiency values stored in the SUMEFF matrix by OPTIMIZE. The second area is the derived variable "SUCCESS" which reflects the outcome of a BATTLE. The last area is the output of the HELBASE model itself.

As a brief review, the values stored in the SUMEFF (5 by 165Ø) matrix are the"average target system sighting efficiency" values corresponding to the"efficiency" of a single point on a specific sphere of operations. For example, SUMEFF (1, 1) contains the "average target system sighting efficiency" value for point 1 on the sphere of operations of weapon type #1. Similarly, the value stored in SUMEFF (4,165Ø) is the efficiency of point 165Ø on the sphere of operations of weapon type #4.

Since these SUMEFF values are used by OPTIMIZE to find the "most efficient" path on which to place the next weapon, it seems reasonable to want these values to be good estimates of their "true" values. A "true" value in the SUMEFF matrix would be found only if SIDEN were called infinite number of times by OPTIMIZE. Since this is not feasible, estimates of the "true" values in SUMEFF must be found within some confidence interval with some degree of confidence that the true value actually lies within that interval.

Each call of SIDEN by OPTIMIZE produce a "target system sighting efficiency" value for all points on all spheres of operation. These values, to be input to the SUMEFF matrix, reflect <u>averages</u> of the efficiency of a given point overall targets (see Chapter III). These values are averaged into the SUMEFF values by OPTIMIZE (again, see Chapter III and also Appendix C). This is why a SUMEFF value is referred to as an "<u>average</u> target system sighting efficiency." This average will converge to the true mean (for each point) as OPTIMIZE calls SIDEN iteratively.

Development of a test procedure which could be used by OPTIMIZE to determine whether enough runs of SIDEN or BATTLE have occurred is common to both cases. The common concern is that the respective means are within specified intervals with a given confidence. Since it could be expected that the number of iterations needed would be less than 3Ø, the objective is to obtain the mean within $\pm\, t_{\alpha/2,n-1}\, s/\sqrt{n}$ or

$$P(\bar{y} - t_{\alpha/2,n-1}\ s/\sqrt{n} \le \mu \le \bar{y} + t_{\alpha/2,n-1}\ s/\sqrt{n}) = 1-\alpha$$

The underlying assumption is that y is distributed normally, and this is addressed below.

If the confidence interval within which the true mean may be found 90% of the time is expressed in terms of the sample mean as:

$$P(\bar{y} - .1\bar{y} \le \mu \le \bar{y} + .1\bar{y}) = .9$$

we are saying that the true mean is within $\pm$ 10% of $\bar{y}$ with a confidence of .9. Therefore,

$$.1\bar{y} = t_{\alpha/2,n-1}\ s/\sqrt{n}$$

We also know that (Ref 15:284) an unbiased estimator for the sample variance is given by

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - \bar{y})^2$$

Therefore, we may say that

$$.1\bar{y} = t_{\alpha/2,n-1}\left[\frac{1}{n(n-1)}\sum(y_i - \bar{y})^2\right]^{1/2}$$

Increasing n from 2 until the left hand side is greater than or equal to the right hand side provides the .9 confidence that the true mean is in the interval $\bar{y} \pm .1\,\bar{y}$.

This "stopping rule" test is somewhat similar to that formulated by Stein (Ref 17: 479 - 481), and can be termed a "sequential approach" to determining the minimum number of iterations.

In the case of the SUMEFF values being discussed, the "target system sighting efficiency" values reflect averages over all targets, and therefore would tend to be normally distributed in accordance with the central limit theorem (Ref17:255), even for averages over 14 or fewer targets.

If the above defined "stopping rule" were to be used to build some confidence in the values in the SUMEFF matrix, storage of the data needed to update the sample mean and variance with each call of SIDEN would prove unmanageable. Random sampling techniques could be used to test fewer than 8250 points with only a slightly lowered confidence in the interval of the mean. For example, random test of about 740 of the 8250 elements of the SUMEFF matrix would yield a probability of .99 that at least one of the elements which has a sample variance in the top (highest) 5% of all 8250 elements would be found (Ref16:63). The calculation for the required number of random samples is given by:

$$n = \ln[1 - p(f)] / \ln(1 - f)$$

where n = Number of random samples (out of 1000),

f = Fraction (percent of population of 1000 within which at least one sample will be found with a probability of p (f).

In this case,

$$n = \ln(1 - .99) / \ln(1 - .05) = 89.78$$

This formulation is constructed for a population of 1000, so we want

$$n = (8250/1000)\, 89.78 \approx 741$$

This procedure is the one recommended for use with the above defined stopping rule in providing some confidence or reliability in the "average target sighting efficiency" values in the matrix SUMEFF.

Since the developed stopping rule is based on the assumptions of a normal (or"near-normal") population, a "goodness-of-fit" test should be run on the output of SIDEN to provide some degree of confidence that normality does in fact exist.

Pritsker and Pegden (Ref18:465-470) discuss a "derived observation" which may assume either a "Ø" or a "1" value. The results of a BATTLE (variable "SUCESS" assumes a value of 1 for a "successful" BATTLE, and a value of Ø for an "unsuccessful" BATTLE) fits this concept very well.

Although the stopping rule derived above could also be applied here, it would be reasonable to expect that the sample variance of the SUCESS variable would dampen to a small value more quickly than some of the "average target system sighting efficiencies" stored in SUMEFF. If applicable tests should fail to reject this hypothesis, the stopping rule applied to the SIDEN outputs averaged into the SUMEFF matrix would also provide assurance that enough BATTLEs have been run to provide confidence in the success or failure of the current weapon system to meet the mission requirements (no. of battles = no. of SIDEN calls).

For the purpose of expedience, SIDEN and BATTLE will each be called three times during simulation runs made for model demonstrations. The results of these experiments must therefore be evaluated with this in mind.

The first area to be investigated in this section is the HELBASE output of a weapon system which meets all mission requirements. The output consists of weapons of specified weapon types placed on specific latitudes or in specific orbits. The primary output parameter of interest is the <u>total number</u> (of all weapon types) of weapons needed to complete the mission.

The confidence intervals imposed on the means of SUMEFF values and the BATTLE variable SUCESS should tend to make the output weapon system deterministic. However, in cases where the placement of the <u>first</u> weapon involves the choice by OPTIMIZE from several weapon paths with nearly equal path efficiencies, the overall number of weapons deployed may change depending on the placement of the first weapon.

This completes both the stochastic event testing discussion and the verification section. The two concepts of model validity left are model credibility and confidence development.

Credibility

Rather than eliciting responses from experts by scenario description and presentation of the simulation results, face validation of HELBASE was accomplished by elicitation of responses from experts concerning the physical processes modeled, the attributes selected, and the design structure of the model.

Several people, each expert in a field associated with the physical processes, attributes, or structure of HELBASE, were consulted in the areas listed in table IV . The refinements and changes listed were made at the suggestion of the corresponding expert.

A second aspect of the credibility part of the validation process is the issue of sensitivity analysis. Model demonstration (Chapter V) incorporates an experimental design which investigates the sensitivity of HELBASE output to changes in target system negation time and target type negation percentages.

An apropos technique for investigating the significance of each of the model inputs would be a 2^k factorial experimental design based on factors which are groups of the 22 individual variables. Even though this would be a time-consuming process, it would definitely have value for the serious model user.

Confidence

A useful tool in building confidence in the performance of submodels PROP and EFFECT is comparison of "one-on-one" (one weapon firing at one target) results with another model. Such models exist in varying degrees of complexity, one fairly accurate one built by Peckham and Davis of the Air Force Weapons Laboratory (AFWL) (Ref[20]). For the "first order

TABLE IV

Face Validation References

Dunne, Edward J., Lt Col	--	Model structure. Sighting efficiency attribute.
Havey , James H., Lt Col	--	Physical process of propagation. Definition of weapon parameters.
Torvik, Peter J.	--	Laser effects physical process.
Wiesel, William E., Capt	--	Orbital relationships.

accuracy" of HELBASE, an accuracy of plus or minus 25% of the AFWL model output would seem reasonable. However, this determination must be made by the user depending on the nature of his decision and experimental design. If necessary, adjustments to submodels PROP and EFFECT could be made.

Finally, the potential user will find that documentation of HELBASE is fairly thourough. A "documentation list" provided by Shannon (Ref 19: 262) calls for the following items.

Flow diagrams of each module and the overall model-- Chapter II.

Description of inputs necessary for executing the program, including: input card number, symbol, definition, whether integer or real, and the field--Chapter V.

Definition of program variables not used as inputs to the program-- Appendix C.

Verbal descriptions of all modules as to purpose and function-- Chapter II.

Input deck setup to run on the computer of interest-- provided separately.

Listing of the program-- Appendix C.

V. Use of the Model

The purpose of this chapter is to demonstrate the use of HELBASE in two fairly typical applications, and to discuss the use of the model in any proper experiment. The general use of the model is covered in the format of an informal "user's guide".

HELBASE Demonstration

Two experimental designs were devised for the model. The first experiment demonstrates the use of HELBASE to pick an "optimum" orbital radius for a specific weapon. The second experiment is a sensitivity analysis concerning two of the HELBASE input variables, an so explores user concerns for a specific model application.

Experiment #1 -- One-Dimensional Optimization of an Orbital Radius. Of the 22 variables which may be input by the user, 21 are held constant for this experiment. The only variable is the orbital altitude of the space-based weapon type being employed.

The hypothetical decision here is that of choosing the best orbital radius for the space-based weapon type. An in-place ground-based weapon type is deployed as shown in Table V . These ground-based weapons constitute an in-being force, and will be used in conjunction with the space-based weapon type in performing the mission. The continued existence and use of these ground-based weapons is certain.

Target type #1, which is 6 targets in 250 NM slightly elliptical orbits, was chosen as the target system. A target type negation percentage of .66 translatesto 4 out of the 6 targets being negated for mission denial. A 60 minute target system negation time gives the in-place ground-based system of 2 weapons and the space-based weapons just 1 hour to negate the 4 targets. Sorting of targets of opportunity by least

Table V

User Inputs for Experiment #1

Ground Based Weapon Type #1

Wavelength (DF)	3800	NM
HEL Power at Source	250,000	Watts
HEL Waist Size at Source	3	Meters
Maximum Firing Cycles Allowed	20	
Maximum Firing Time per Operating Cycle	10	Seconds
Recycle Time	120	Seconds
Maximum Range Allowed	∞	Default
Probability of Failure	0	
Mode Number	1	
Altitude	0	
Absorption Coefficient	.07	KM^{-1}

Space-Based Weapon Type #2

Wavelength	10,600	NM
HEL Power at Source	50,000	Watts
HEL Waist Size at Source	1	Meter
Maximum Firing Cycles Allowed	5	
Maximum Firing Time per Operating Cycle	20	Seconds
Recycle Time	60	Seconds
Maximum Range Allowed	∞	
Probability of Failure	0	
Mode Number	3	
Altitude	500	NM (17,812 KM)
Absorption Coefficient	.143	KM^{-1}

Target Type #1 (6 targets in 250 NM slightly elliptical orbits)

Mission Data

Target Type	1	
Target Type Negation Percentage	.66	(4 targets)
Target System Negation Time	60	minutes
Target Type Priority		Default (1)

Battle Management Data

Target Type	1
Firing Priorities	Default (4)
Sorting by Irradiation Time	Yes (1)

irradiation time is employed as a tactic. Obviously, assigning firing priorities is not appropriate since only one target type was selected for this experiment.

The decision makers are faced only with the selection of the circular orbit radius of the space-based weapons in this case. The decision has already been made to deploy the space weapons to complement the in-being ground weapons, and all of the space weapons are to be placed at the same orbital radius. The objective is to find the orbital radius for the space weapons which causes the fewest number of space weapons to be needed to meet the mission requirements.

The experimental design is based on the one-dimensional Golden-Section search technique (Ref 16:32-35). Of the class of one-dimensional search techniques based on the assumption of unimodality, the Golden Section technique is the second most efficient in terms of the number of observations needed. It is only slightly less efficient than the Fibonacci technique. The observations consist of the number of space weapons required along with the radius of the weapons input. So the "x" (independent) variable is the input radius, and the "f(x)" (output) response is the number of space weapons required to meet the mission requirements.

As stated above, the Golden Section search technique is based on the assumption that the response "f(x)" is unimodal over the range of "x" being considered. In other words, the f(x) response must exhibit one of four kinds of behavior as x varies between its minimum and maximum values. The response f(x) must: 1) strictly increase, 2) strictly decrease, 3) strictly increase to a maximum and then strictly decrease, or 4) strictly decrease to a minimum and then strictly increase. In all but the third case, the optimum solution will be at the minimum or maximum value of x.

The literature does not offer a method of estimating the unimodality of a simulation response of an unknown character. There is a rough intuitive reasonableness in assuming unimodality in this case. It seems justifiable that one and only one maximum would exist for the HELBASE response for a range of X from 5ØØ to 17,872 KM. If, on the other hand, the target type chosen had been type #3 (5ØØ NM, 926.5 KM circular orbits), and X were allowed to vary from 5ØØ to 17,872 KM, an assumption of unimodality would not seem reasonable. The existence of local minima or maxima as X moves from below to above the target system altitude would seem probable.

In the case under consideration, the target system is at 463.25 KM, and the weapon altitude is allowed to vary from 5ØØ to 17872 KM. So local minima or maxima would not be expected. As a rudimentary check on the unimodality assumption, the response of HELBASE can be inspected during the Golden Section search procedure.

This procedure is based on the simple premise of iteratively decreasing the size of the feasible interial of X until an optimum value X* can be approximated with some degree of accuracy. The initial inter al (5ØØ, 17872) is divided into overlapping subintervals of length .618 of the interval length. The two subintervals are measured from opposite ends of the initial interval. That is, point 1 is located 10735.9 KM from the lower end of the interval, and point 2 is located 10735.9 KM from the upper end of the interval. For the initial interval, point 1 is at 11235.9 KM, and point 2 at 7136.1 KM. HELBASE responses (number of weapons) are then obtained for each altitude. If the HELBASE response for an orbital radius of 7136.1KM (f(7136.1) were less than f(11235.9), the region of the interval (5ØØ, 17872) from 5ØØ to 7136.1

need not be considered further. So, we take as the next inter al to be evaluated (7136.1, 17872). Similarly, if f(7136.1) were greater than f(11235.9), the region of (5ØØ, 17872) from 11235.9 to 17872 need not be considered further, and we would take as the next interval (5ØØ, 11235.9). Note that in both cases, the initial interval would be decreased 38.2% (.618 of the initial length), and that one of the responses needed for the evaluation of the next interval would have already been obtained.

The number of iterations of the above procedure is related to the size of the "final" interval (within which the final value of X will lie) is

$$N = \frac{\ln L_N - \ln L_o}{\ln .618} + 1$$

, where

N is the number of model responses needed,

Ln is the length of the final (Nth) interval, and

Lo is the length of the initial interval.

If the objective is to find a final interval of length 1ØØØ KM which is guaranteed to contain the maximum X* under the assumption of unimodality, 6 model responses will be needed. That is, $N = \frac{\ln(1000) - \ln(17372)}{\ln(.618)} \approx 6$

In addition, a refinement of the final X approximation to X* can be found by graphing the functional responses against the input X's and interpolating (or extrapolating) through the final interval.

Analysis of the results of this experiment is difficult due to the single variable nature and the small number of responses. The "inference space" of concern here is fairly restricted. The "optional radius" found suffers several degrees of approximation. It endures not only the degree of approximation caused by HELBASE assumption, accuracy, scope and limitations, but an additional degree inferred by the unimodality assumption. Part of the implied inference space for the results of this experiment is that the optional radius found can only be "trusted" for the system configuration used. That is, the number and placement of the space weapons cannot be <u>assumed</u> to be independent of the number, characteristics and placement of the ground weapons. Simple tests, such as statistical significance tests of varying the ground-based weapon parameters could be used to reject the significance of changes in those parameters. In this way an extension of the inference space in which the optimum radius result could be considered valid could be obtained.

<u>Experiment #2 -- Two Factor Sensitivity Analysis</u>. In general, the interrelationship between any two factors in HELBASE is dependent upon the values assigned to the other 2Ø factors. Therefore, sensitivity analysis can only have meaning within defined ranges of the factors of interest with the rest of the input variables being held constant.

The two factors being considered here are the target system negation time and the target type negation percentage. In the decision situation described below, the target system negation time will be varied from 1 hour and 3Ø minutes to two hours, and the negation percentage for both target types will be varied from .6Ø to .7Ø.

The mission envisioned in this case is to deny a potential enemy the use of a target system consisting of 3 satellites in 500 NM (926.5 KM) circular orbits (type 3) and 6 satellites in 250 NM (463.25 KM) slightly elliptical orbits (type 1). The only HEL weapon available for deployment is a deuterium flouride system nearing operational testing as a ground battle station.

The decision has been made to deploy as many of these systems as are "needed".

Weapon parameters are listed in Table VI.

It has been decided that it is roughly "10 times more important" to negate the type 1 targets than the type 2. Therefore, a target type priority of 10 has been assigned to the 6 type 1 targets. In conjunction with this, target type 1 is assigned a firing priority of 1. The tactic of firing at a target which requires a shorter irradiation time for target negation is used.

The only decision variables not "nailed down" at this point are the negation percentage and the target system negation time.

The decision situation is as follows. We will assume that HELBASE was run with the target type negation percentage set to .7 and the target system negation time set to 1 hour and 30 minutes. The model output indicated that x weapons were needed on various latitudes. A review of this deployment scheme yielded a concern over whether the x number of weapons could be reduced by increasing the allowed mission time or by decreasing the percentage of each target type required to be negated, or perhaps some of both.

The lowest percentage that the decision maker will accept as reasonable is .6, and the maximum target system negation time is 2 hrs. A .6

Table VI

User Inputs for Experiment #2

DF Weapon

Wavelength	38ØØ NM
HEL Power at Source	50,000,000 watts
HEL Waist Size at Source	3 meters
Maximum Firing Cycles Allowed	1Ø
Maximum Firing Time per Operating Cycle	1Ø seconds
Recycle Time	6Ø seconds
Maximum Range Allowed	5ØØØ KM
Probability of Failure	Ø
Mode Number	1
Altitude	Ø
Absorption Coefficient	.Ø7

Target Types #1 and #3.

Mission Data

Target Type #1:	Target Type Negation Percentage	.6Ø to .7Ø
	Target System Negation Time	9Ø to 12Ø
	Target Type Priority	1Ø
Target Type #3:	Target Type Negation Percentage	.6Ø to .7Ø
	Target System Negation Time	9Ø to 12Ø min.
	Target Type Priority	1

Battle Management Data

Target Type #1:	Firing Priority	1
Target Type #2:	Firing Priority	4
Sorting by irradiation Time:		Yes

percentage translates to 2 out of the 3 type 3 satellites,

$(.6 \times 3 = 1.8 \approx 2)$, and

4 out of the 6 type 1 satellites. The .7 percentage translates to all of the type 3 satellites and 5 of the 6 type 1 satellites. An examination of these alternatives reveals that we are actually concerned with .66 percentages for the low end and .83 (type 1) and 1.00 (type 3) for the high end. This small revelation is even more palatable to the decision maker, since he does not have to accept an actual negation percentage of .6, and the target type negation percentage alternatives are set at .6 and .7 for both target types.

The decision maker regards the increasing of mission time to two hours and the decreasing of negation percentage to .6 as equally degrading to the mission. Therefore, an "equi-valued" pair of alternatives is as follows:

Alternative #1: Negation percentage at .6, mission time at 90 minutes,

Alternative #2: Negation percentage at .7 mission time at 120 minutes.

Since we have two factors at two levels, it would seem reasonable to pursue a factorial experimental design. A full factorial two factor-two level design (Ref B = 163-165) requires that we also evaluate the "high-high" and "low-low" combination in order to allow assessment of factor significance and any interrelationships between the factors. Therefore, we need two more experimental alternatives:

Alternative #3: Negation percentage at .7, mission time at 90 minutes,

Alternative #4: Negation percentage at .6, mission time at 120 minutes.

Of course, alternative #3 is the original factor combination which produced the X weapon requirement. This data point can be used as one of those needed for this experiment. Inclusion of these alternatives in the full factorial design will allow an evaluation of the other stated alternative "or perhaps some of both".

The experimental design is depicted in figure 21 . Since the HELBASE output (number of weapons) would be expected to yield fairly constant responses for any combination of the factor levels, Three responses for each combination will be obtained. Therefore, 12 model runs will be needed in order to evaluate all combinations of factors with two replications. See Table VII for a listing of the input cards.

The implied model underlying this 2^2 full factorial experimental design is

$$x_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ijk}$$

where

i is the level of the negation percentage,

j is the level of mission time,

k is the kth observation at factor levels $\bar{i}$, $\bar{j}$,

μ is the mean of <u>all</u> responses,

α_i is the contribution of negation percentage at level i,

β_j is the contribution of mission time at level j,

$(\alpha\beta)_{ij}$ is the contribution of the interaction between negation percentage at level i and mission time at level j, and

ϵ_{ijk} is a random error term (unexplained contribution).

The analysis of the experimental results is done in a analysis of

TARGET TYPE NEGATION PERCENTAGE		TARGET SYSTEM NEGATION TIME 90	120
	.6	x_{111} x_{112} x_{113}	x_{121} x_{122} x_{123}
	.7	x_{211} x_{212} x_{213}	x_{221} x_{222} x_{223}

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Negation Percentage	1	SS_A	$MSA=SS_A$	MSA/MSE
Mission Time	1	SS_B	$MSB=SS_B$	MSB/MSE
Interaction	1	SS_{AB}	$MSAB=SS_{AB}$	MSAB/MSE
Error	8	SS_E	$MSE=\frac{SSE}{8}$	
Total	11			

Fig 21. Experiment #2 Design

TABLE VII

Input Cards Used for Experiment #2

Note: All values are real, and all cards are free-formatted.

LOW-LOW

CARD #	FIRST REPLICATION		(LOW-LOW)
1	8972.		
2	1.		
3	38ØØ	5ØØØØØØØ.	3. 1Ø. 1Ø. 6Ø. 5ØØØ. Ø. 1. Ø. .07
4	1.		
5	3.		
6	99.		
7	1. .6 9Ø. 1Ø.		
8	3. .6 9Ø. 1.		
9	1. 1. 1.		
10	3. 4. 1.		
11	7/8/9		

Legend for the Above Data Set

CARD #	LEGEND
1	(8972.) Random number seed.
2	(1.) Number of weapon types input.
3	(38ØØ.) Wavelength in nanometers.
	(5ØØØØØØØ.) Weapon power in watts.
	(3.) HEL waist size in meters.
	(1Ø.) Maximum allowed firing cycles.
	(1Ø.) Maximum firing time per cycle in seconds.
	(6Ø.) Recycle time in seconds.
	(5ØØØ.) Maximum range in kilometers.
	(Ø.) Probability of weapon failure.
	(1.) Mode number.
	(Ø.) Weapon altitude in kilometers.
	(.Ø7) Absorption coefficient in kilometers^{-1}.
4	(1.) Target type 1 selected.
5	(3.) Target type 3 selected.
6	(99.) Target type selection terminator.
7	(1.) Target type 1.
	(.6) Negation percentage for target type 1.
	(9Ø.) Target system negation time in minutes.
	(1Ø.) Target type 1 priority.
8	Same as card #7.
9	(1.) Target type 1.
	(1.) Firing priority against target type 1.
	(1.) Sorting by irradiation time selected.
1Ø	Same as card #9.
11	End of record.

CARD #	SECOND REPLICATION	(LOW-LOW)
12	5555.	
13		
.	Same as above.	
.		
.		
22		

CARD #	THIRD REPLICATION	(LOW-LOW)
23	14670927.	
24		
.	Same as above.	
.		
.		
33		

LOW-HIGH

CARD #	FIRST REPLICATION	(LOW-HIGH)
34	4492.	
35	1.	
36	3800. 50000000. 3. 10. 10. 60. 5000. 0. 1. 0..0 7	
37	1.	
38	3.	
39	99.	
40	1. .6 120. 10.	
41	3. .6 120. 1.	
42	1. 1. 1.	
43	3. 4. 1.	
44	7/8/9	

CARD #	SECOND REPLICATION	(LOW-HIGH)
45	92929292.	
46		
.		
.	Same as above.	
.		
55		

CARD #	THIRD REPLICATION	(LOW-HIGH)
56	197555.	
57		
.	Same as above.	
.		
.		
66		

HIGH-LOW

CARD #	FIRST REPLICATION	(HIGH-LOW)
67	18.	
68	1.	
69	38ØØ. 5ØØØØØØØ. 3. 1Ø. 1Ø. 6Ø. 5ØØØ. Ø. 1. Ø. .Ø7	
7Ø	1.	
71	3.	
72	99.	
73	1. .7 9Ø. 1Ø.	
74	3. .7 9Ø. 1.	
75	1. 1. 1.	
76	3. 4. 1.	
77	7/8/9	

CARD #	SECOND REPLICATION	(HIGH-LOW)
78	111222333.	
79		
.		
.	Same as above.	
.		
88		

CARD #	THIRD REPLICATION	(HIGH-LOW)
89	333222111.	
9Ø		
.	Same as above.	
.		
.		
99		

HIGH-HIGH

CARD #	FIRST REPLICATION	(HIGH-HIGH)
1ØØ	66666.	
1Ø1	1.	
1Ø2	38ØØ. 5ØØØØØØØ. 3. 1Ø. 1Ø. 6Ø. 5ØØØ. Ø. 1. Ø. .Ø7	
1Ø3	1.	
1Ø4	3.	
1Ø5	99.	
1Ø6	1. .7 12Ø. 1Ø.	
1Ø7	3. .7 12Ø. 1.	
1Ø8	1. 1. 1.	
1Ø9	3. 4. 1.	
11Ø	7/8/9	

CARD #	SECOND REPLICATION	(HIGH-HIGH)
111	7777.	
112		
.		
.	Same as above.	
.		
121		

CARD #	THIRD REPLICATION	(HIGH-HIGH)
122	9876543.	
123		
.		
.		
.	Same as above.	
132		

variance format, discussed widely in the literature (Refs 15: 472-477; 19: 162).

User's Guide

The above two experimental designs serve to exphasize some aspects of using the HELBASE model in the support of specific decisions. Because HELBASE was conceived and designed to be a flexible tool for the decision maker, analyst or manager, amenable to a variety of experimental designs in support of a wide range of decisions, a certain amount of responsibility for proper use lies with the user.

In addition to the normal precautions and care which should be taken with the use of any model, the HELBASE user must be aware of certain pitfalls and biases which must be warded against. These biases can occur due to improper use of the 22 input variables, or through misunderstanding of the inference space surrounding the model output. Accordingly, this informal "user's guide" is divided into two sections--"Pre-Analysis and Experimental Design", and "Post-Analysis".

Pre-Analysis and Experimental Design. The experimental designs available to the user are not limited by the HELBASE model structure. However, after the user thoroughly understands the decision situation for which the experiment will be carried out, has satisfactorily expressed the experimental objective, and has designed the experiment, a few other considerations should be made before the experiment is run. These considerations are related to the physical processes modeled, the interactions among the input variables, and the sensitivity of the model output to the decision variables of concern.

First, the user must have confidence in PROP. Especially critical is a check on the possibility of thermal blooming for ground- or air-based weapons. In addition to the thermal blooming approximation technique referenced in Chapter I, a propagation model such as the one proffered by Peckham and Davis (Ref 20) can be used to build confidence in the HELBASE submodel PROP in any specific application.

An additional check in this area would be assurance by the user that the laser power, wavelength and location combinations input will yield a lethal effect on a significant number of the targets. HELBASE cannot choose a "most efficient" path if no weapon negations are feasible. In a case such as this, the model would terminate execution when OPTIMIZE attempted to find the maximum of a set weapon path efficiencies which are all equal to zero.

Second, the values of all non-decision variables in the 22 input variable set must be chosen with care. Many, if not most, can be assigned values which are reasonable for the decision situation under consideration.

Due to the generally unexamined nature of interrelationships among the 22 input variables with respect to the HELBASE output weapon system, even acceptance of model default values should be done with care. For example, acceptance of the default target type negation percentage of .8 could very well affect the significant sensitivity range of the target system negation time. If the sensitivity of the HELBASE output to the mission time were inportant to the user's experiment, this unwanted and unknown (to the user) bias could well affect model output as well as the resulting decision.

The general area of sensitivity analysis is the third and last area in which some caution should be shown by the user. Since a generalized sensitivity analysis and definition of interrelationships among all 22 input variables would prove an intolerable computational feat, the potential user may find it advisable to conduct a restricted sensitivity analysis over the decision variables chosen for the specific experiment. An approximation of the individual and joint effects can also be calculated as described in experiment #2.

Post-Analysis. In conjunction with the traditional statistical analysis performed for the user's experimental design, two additional areas of concern should be considered after the experiment has been run.

Because the normal purpose of a simulation experiment is to aid a decision maker, the user should insure that the inference space (the combination of model assumptions, limitations, scope and accuracy with the user's specific choice of constant as well as decision variables within the experimental design) has been extended and is valid over the decision situation.

The second major consideration that may have value to a user is an analysis to selectively improve upon the "baseline" HELBASE weapon deployment scheme. The output of the model is termed "baseline" because some judicious adjustments of the weapon locational parameters produced by HELBASE can, in many cases, improve the performance of the weapon system. As discussed in Chapters II and III, HELBASE places ground- and air-based weapons on latitudes, and defines only five of the six orbital parameters for space-based weapons.

This means that, for latitudes with more than one weapon assigned, the exact locations of the weapons around the latitudinal circle is treated randomly by the model, with no effect on the "baseline" capability of the weapon system to satisfy the mission requirements. For example, consider a HELBASE output which places three ground-based weapons at theta = 30° (60 N latitude). Random treatment of the locations of the three weapons on the 60° North latitude implies that the three weapons may be placed virtually anywhere around the latitudinal circle while retaining the "baseline" capability to meet the mission requirements. Therefore, thoughtful placement of the three weapons may yield significant improvement in weapon system performance. In this example, distributing the three ground-based weapons at 120° intervals around the latitudinal circle could be expected to improve the performance of the weapon system.

Similar improvements may be expected for air-based weapons. In addition to the distribution of weapons around the latitudinal circle described above, air-based weapons may be flown off the latitudinal path so as to more efficiently intercept targets in response to the known target locations at the initiation of hostilities. This technique would be expected to yield improvement in weapon system performance.

The basic reason behind this type of performance improvement is that the model output weapon system is capable of satisfying mission requirements with the time of hostilities initiation being random.

The unspecified parameter in the HELBASE selection of space-based weapons is the true anomaly at epoch. This sixth orbital parameter is again treated randomly by HELBASE during the building of the output weapon system. A user may find it advantageous to define true anomalies for space weapons which cause "phase relationships" among the weapons.

The effect on weapon system performance of making the above adjustments in the deployment parameters may be measured by inputting this weapon system into a BATTLE and noting any improvement (decrease) in the time taken to satisfy the mission requirements. It must be noted that some modification of the current model would be necessary to allow this type of HELBASE employment.

This chapter has examined two experimental designs which would be considered typical for use with HELBASE. In addition, considerations which could improve the efficiency and validity of any use of HELBASE were offered in the "User's Guide" section. The last chapter summarizes the thesis effort, investigates the implications and possible value of the deployment of the model, and offers recommendations to improve its usefulness.

VI Conclusions and Recommendations

The most important consideration here is whether the thesis effort met its objective, and whether the HELBASE model serves its stated purposes. In addition to these points, the potential utility of the model is evaluated.

Recommendations for model improvement are many. The most appropriate are reviewed here, and a representative portion of the rest is left to Appendix B.

Summary

From the thesis objective and problem statement, the model HELBASE was conceptualized in modular form. The physical processes modeled by PROP and EFFECT formed the accuracy lower bound, and the rest of the model was constructed with this in mind.

In addition to these physical processes concerning laser beam propagation and the effect on the target, three basic things were needed to meet the thesis objective. An appropriate quantitative attribute to measure the "efficiency" of weapon placement was developed and is employed in submodel SIGHT. A methodology for using this attribute in picking a "most efficient" weapon path was then constructed. This methodology is the basis of submodels OPTIMIZE, SIDEN, TARGET, and SPHERE. After the "most efficient" path was selected and a weapon placed in this path, a way to measure the degree to which this weapon and all others previously placed could satisfy mission requirements was needed. Submodel BATTLE was therefore developed.

The aggregation of these submodels, along with an input section, forms the model HELBASE. An external program called ORB was written for the sole purpose of defining orbital points (see Appendix C).

Validation and verification of the model was carried out with the exception of stochastic tests on the variables generated by submodel SIDEN and the distribution of the BATTLE response.

The model was employed in support of specific hypothetical problems. In this way, the complexities of HELBASE use were explored and discussed.

Thesis Objective and Model Purpose

As stated in Chapter I, "The purpose of this thesis is to properly define the appropriate attributes of merit and to develop a simulation model which would give a decision maker a flexible tool in investigating the effects of these attributes on specific space defensive missions."

The model HELBASE is based upon the efficiency attribute developed in Chapter III. The range of model applications can be appreciated by inspection of the uses shown and discussed in Chapter V.

Model Utility

The potential utility of the model must be judged in comparison with other existing tools which could be used for the same purpose. A comprehensive literature search yielded no "many-on-many" models of this nature. It would therefore have to be concluded that HELBASE can only add to the overall understanding of the "system" being investigated. Better understanding of the long range impact of design and development decisions, deployment options and employment tactics seem clearly justifiable. In fact, with proper pre- and post-analysis (See Chapter V), the number of potential uses of HELBASE seems almost unlimited.

Recommendations

The recommendations discussed here will be limited. See Appendix B for an expanded discussion.

Target Types. Obviously the use of HELBASE by a serious analyst would require the changing of the target types from the four representative cases to "real" target types selected by the user.

Space-Based Weapons Orbital Selection. Allowing the input of specific elliptical orbits for weapons would seem to have value. Expansion of the generalized optimization technique to include elliptical orbits is discussed in Appendix B.

Battle Tactics. Additions to the available options in battle management data would give a user more tactical options. Appendix B includes discussions of an option to reserve battle stations to be committed at a specific time after the initiation of hostilities, and an option to prioritize the commitment of available battle stations.

Cost Considerations. In addition to a look at accounting for the fixed costs associated with deploying the first weapon of a given weapon type, an alternate "sighting efficiency" attribute is discussed. See Appendix B.

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APPENDICES

A. Data Reduction for Laser Effects

Representative satellite vulnerability data was supplied by the Space Systems Division of the Air Force Systems Command's Foreign Technology Division. Although the data used for the four HELBASE target types is not "real" data for any particular satellite system in the real world, it is representative of the "real" data.

This data was supplied in the form shown in figure 22 . The fluence (in joules per square centimeter) induced into the target is measured on the ordinate. The time (in seconds) that it takes the fluence to be induced is measured on the abscissa. A point on the graph represents "failure" of a satellite subsystem at the fluence and time shown.

Since the information needed was "time to satellite negation" at some laser intensity (watts per square centimeter), the data was transformed. The transformation function was

$$I = \frac{F}{t} \text{ , where}$$

I = Laser intensity, (watts per square centimeter)

F = Fluence, (joules per square centimeter)

t = Irradiation time (seconds).

"I" was then placed on the ordinate, with "t" again on the abscissa (see figure 22).

In order to accomplish this transformation, several points were taken from supplied data (see table VIII), and transformed. The problem then became one of approximating the transformed data by a functional representation.

Table VIII

Representative Data Transformation

REPRESENTATIVE DATA		TRANSFORMED DATA	CONSTANTS		
TIME	FLUENCE		a	b	c
TARGET TYPE #1			.000.52	-.25	38
10	550	55			
20	600	30			
50	850	13			
100	1400	14			
TARGET TYPE #2			.02	-5.6	420
10	4200	420			
20	4300	220			
50	5000	100			
100	6200	62			
TARGET TYPE #3			.00012	-.7	73
5	500	100			
10	550	55			
20	560	28			
50	650	13			
100	780	8			
TARGET TYPE #4			.00052	-.25	38
2	350	175			
5	360	72			
10	370	37			
20	390	20			
50	460	9			
100	640	6			

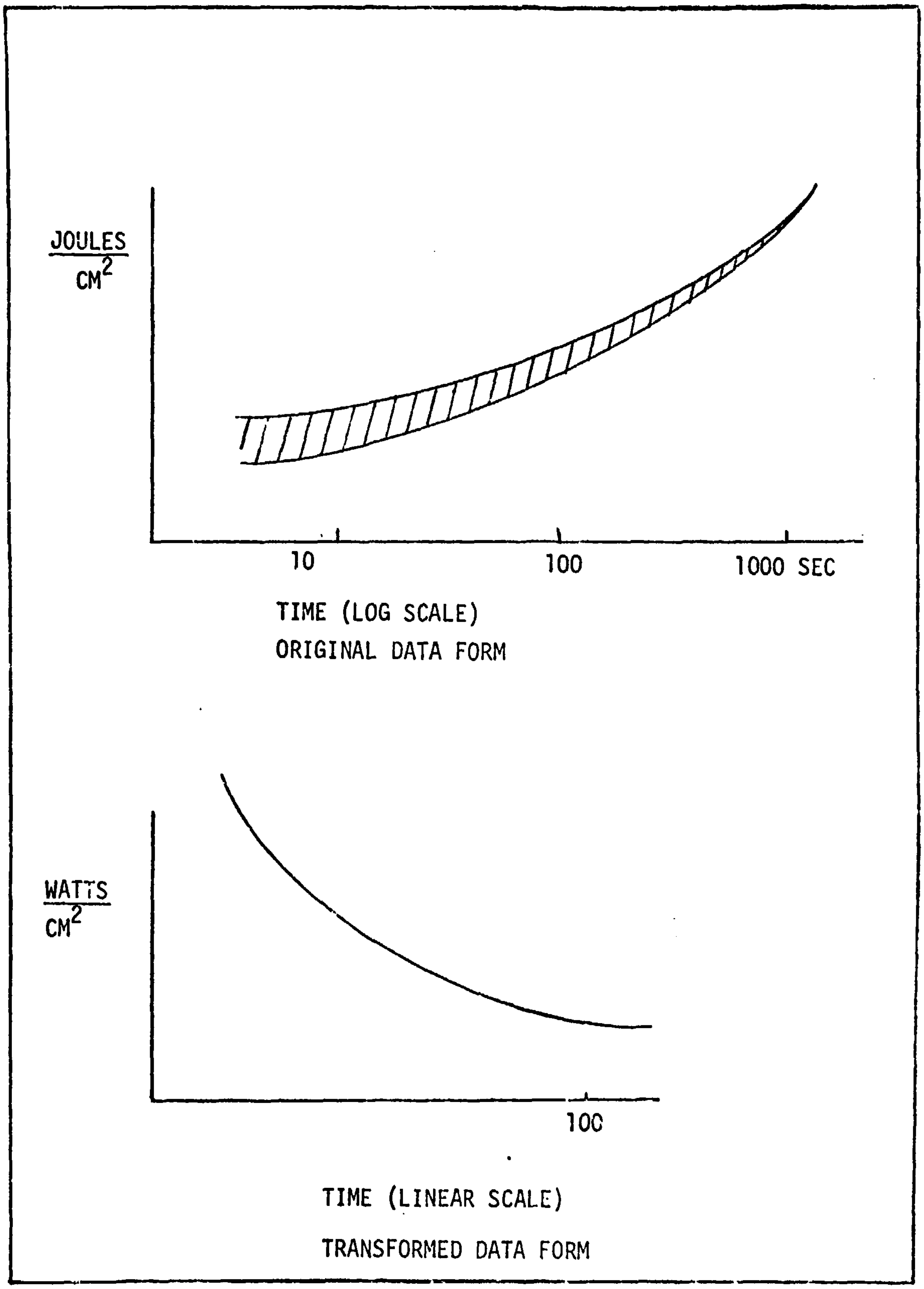

Fig 22. Representative Data Form

In all four cases, a least squares quadratic polynomial was fit to the transformed data (Refs21;122-125, and22:135). TableIX also shows the quadratic constants generated by the least squares quadratic fit.

The solution for the negation time is given by:

$$t = \frac{-b - \left[b^2 - 4ac + 4ad\, I_j \sqrt{1/\lambda_j} \,\right]^{1/2}}{2a}$$

where

t = Irradiation time required for target negation,

a, b, c are quadratic constants,

d is a constant related to the data base,

I_j is the intensity of the beam at the target, and

λ_j is the wavelength of the beam.

Feasible solutions of this function are limited to times from 1/10th of a millisecond to 100 seconds. Therefore, values of I_j and λ_j which would yield a t of less than .0001 seconds or more than 100 seconds are not accepted by submodel EFFECT (see Appendix C). If the calculated negation time would have been less than .0001 seconds, it is assigned the value of .0001 seconds. If the calculated negation would have been more than 100 seconds, it is assigned the value of 9,999,999 seconds. This large value will insure a target sighting efficiency value of zero in submodel SIGHT.

B. Recommendations

The recommendations offered here are divided into sections describing the general area of improvement.

Selection of Orbital Weapons

1. Inclusion of elliptical orbits. When only circular orbits are considered for space weapons, two of the six orbital elements are trivialized. That is, the agreement of perigee is meaningless and the eccentricity is zero. If we wish to consider elliptical orbits in the generalized optimization scheme, we therefore pick up these two additional degrees of freedom. When we have 825 orbital possibilities for a given circular orbit radius, we could have 267,300 possibilities for a given elliptical orbit semi-major axis. This is derived from a choice of eccentricity from 1. to .9 and a 5^{o} incremental choice of agremeent of perigee. (825 x 9 x 36 = 267,300). Due to the large number of orbital possibilities, even searching through them for a "most efficient path" would be expensive.

Therefore, a random search technique over the 267,300 possibilities could be used to find at least one in the top 5% with a probability of .9. This would require exactly 12000 samples of the 267,300 possibilities. We could feel fairly confident that the best orbit thus found would be near the global maximum, and a multi-dimensional search for the maximum could be initiated with the best orbit from the random search as the starting point.

The point is that extension of the model to include elliptical weapon orbits is very feasible.

2. Exclude a range of orbital inclinations from consideration for a given space weapon type. A feasible scenario for this option would involve the

inability of available launch vehicles to place the weapons into highly inclined orbits. A restriction could be placed on the SUMEFF matrix and the search over the values by OPTIMIZE.

4. Allow orbital "reflectors". Allowing the pre-hostility placement of orbital reflectors for the purpose of reflecting laser beams to target satellites has been proposed. The submodels SIGHT, OPTIMIZE, and BATTLE could be expanded to include this interesting concept.

5. Expansion of the "probability of failure" input. The simple probability of weapon failure (not used in the current model) input could be expanded to a specific reliability function and failure rate for each weapon type. This would aid significantly in cost/benefit analyses concerning weapon reliability.

6. Limit the number of weapons for a specific weapon type. Justification for this option could be limits on command and control capabilities, political constraints, or production limitations.

Battle Tactics

Capability to commit weapons at a discrete time. In the case of"hidden" weapons, the tactic of delaying weapon use could be evaluated. This would only require the addition of another column to the TIME matrix used in BATTLE.

7. Add weapon use priorities. A possible tactic may be to use weapon X only against target types A, B, and C. Additionally, weapon X could be constrained to be used first against target type B, secondly against A, and lastly against C.

8. Include more than one weapon in a battle station. Common system sharing could justify this option in many cases.

9. Define a probability of kill (Pk). A Pk based on pointing and tracking accuracies and/or target maneuvering could be developed (see below).

10. Allow target to maneuver to avoid irradiation.

11. Allow different negation times for each target type. It seems perfectly feasible that a user may desire one target type to be negated before others. For example, it may be desirable to insure negation of target type A at the two hour point, and type B at the ten hour point. "Mission accomplishment" would require that both of these conditions be met (or bettered).

12. Weapon slew rate restriction. Calculation of required weapon slew rate (cross-track angular velocity) could be added to submodel SIGHT. Exceeding an input maximum would cause "no sighting" for that encounter.

Cost Considerations

13. Revise basic "sighting efficiency" attribute. An attribute to measure the "most efficient" weapon path could be developed in terms of "cost efficiency". The "most efficient" path would then be the most "cost efficient" path.

As discussed by several authors, "costing out" of alternatives appeared to be one of the few viable correction factors available (Refs 3:125-127, 4:57-59). It is plausible that the "cost per joule" of an HEL beam from a ground-based weapon would tend to be much less than the "cost-per-joule" of a beam from a satellite weapon. The correction factor would then be to "cost out" the total energy required to negate a target. The relative energy unit costs would be functions of the HEL energy technology of each weapon type.

So the attribute to measure the "most efficient" placement of weapons would be cost effectiveness (actually the reciprocal of cost). Relative costs could be assigned to ground-, air-, and space-based weapon energy. Relative costs of output energy must be functions of total weapon life cycle costs over equal weapon lifetimes.

14. Add fixed cost of using the first weapon of a weapon type. For some problems, it may be apropos to consider the relevant fixed costs (research, development, testing) of adding the first weapon of a previously unused weapon type to the weapon system.

C. HELBASE Listing

```
      PROGRAM HELBASE(INPUT,OUTPUT)
      INTEGER [illegible],TT[illegible], [illegible], [illegible],[illegible]
      REAL [illegible],[illegible],[illegible], [illegible], TOT,[illegible]
      DIMENSION [illegible],[illegible],MISSION(4,4),TACTIC(4,3),D(4),
     C SHOTFR(5,155),[illegible],Y(5,[illegible]),Z(5,[illegible]),XT(14),YT(14),
     C ZT(14),[illegible],[illegible],[illegible],[illegible],DAT(5,325),
     C [illegible](32,14),[illegible],[illegible],[illegible],[illegible],[illegible](32,14),
     C [illegible](14,1[illegible])
C     ******************************************************
C
C
C     RANDOM NUMBER GENERATOR SEED.   (REAL NO.)
C
C     USE A SEPARATE CARD WITH ONLY THE REAL RANDOM NUMBER SEED ON IT.
C
C
      READ*,SEED
      CALL RANSET(SEED)
C     ******************************************************
C
C     THE FIRST SECTION IS DESIGNED TO ACCEPT USER INPUTS
C     INPUTS ARE READ IN THE FOLLOWING ORDER...
C        WEAPON TYPES
C        TARGET TYPES
C        MISSION DATA
C        BATTLE [illegible] DATA
C     ******************************************************
C
C
C     WEAPON TYPES
C
C     UP TO 5 DIFFERENT WEAPON TYPES MAY BE INPUT, 1 CARD PER WEAPON TYPE.
C
C     THE FIRST [illegible] IS THE NUMBER OF WEAPON TYPES TO BE INPUT
C     EACH CARD [illegible], [illegible] SEPARATED BY COMMAS OR
C     [illegible]
C     [illegible]
C     THE [illegible] ARE [illegible] FOLLOWS...
C        LA[illegible]........[illegible]                    ([illegible]ATORY)
C        PO........[illegible] ([illegible])   ([illegible]ATORY)
C        WO........[illegible] AT [illegible],            ([illegible]ULT [illegible]TIER.
C        [illegible]......[illegible] ([illegible])   ([illegible]ULT [illegible] CYCLES
C        [illegible]......[illegible] ([illegible])
C                 [illegible]
C        [illegible]......[illegible] ([illegible]ULT [illegible]S)
C        RAN[illegible]......[illegible] IS A FUNCTION OF
C                 [illegible] [illegible] CAPABILITY.
C                 [illegible]
C        [illegible]........[illegible]
C        [illegible]........[illegible] ([illegible]ATORY)
C        [illegible]........[illegible]
C                                    [illegible]
C
C
C        [illegible]
C
C
```

```
      READ*,NTNO
      NONT=NTNO
      IF(NONT.GT.5)PRINT*,"*****TOO MANY TARGET TYPES INPUT*****"
C
C     ZERO OUT THE STORAGE LOCATIONS FOR THE WEAPON MATRIX.
C
      DO 5 I=1,11
      DO 7 J=1,5
      WEAPON (I,J)=0.
 7    CONTINUE
 5    CONTINUE
      DO 10 I=1,NONT
      READ*,(WEAPON(IN,I),IN=1,11)
      IF(WEAPON(3,I).EQ.0.)WEAPON(3,I)=1.
      IF(WEAPON(4,I).EQ.0.)WEAPON(4,I)=9.[illegible]
      IF(WEAPON(5,I).EQ.0.)WEAPON(5,I)=9.[illegible]
      IF(WEAPON(7,I).EQ.0.)WEAPON(7,I)=9.[illegible]
      IF(WEAPON(1[illegible],I).EQ.0.)WEAPON(1[illegible],I)=[illegible]
 10   CONTINUE
C
C
C     ********************************************
C
C     TARGET TYPE INPUTS
C     T MATRIX FOR DEVELOPMENTAL TARGET SYSTEM
C     4 TARGET TYPES, 14 TOTAL TARGETS
C     T(I,1) IS TARGET TYPE NUMBER.
C     T(I,2) IS SEMI-MAJOR AXIS OF ORBIT.
C     T(I,3) IS ORBITAL ECCENTRICITY.
C     T(I,4) IS ORBITAL INCLINATION.
C     T(I,5) IS LONGITUDE OF [illegible]
C     T(I,6) IS ARGUMENT OF PERIGEE.
C     T(I,7) IS EPOCH DATA [illegible]
C     T(I,8) IS EPOCH DATA POINT [illegible]
C     T(I,9) IS EPOCH DATA POINT [illegible]
C     T(I,10)IS MEAN ANOMALY.
C
C     ZERO ALL T(I,11) VALUES.
C
      DO 99 I=1,14
      T(I,11)=0.
 99   CONTINUE
C
C
C
C
C     TYPE 1 IS [illegible] TARGETS IN [illegible] CIRCULAR [illegible]
C
      DO 11[illegible] I=1,[illegible]
      T(I,1)=1.
      T(I,2)=[illegible]
      T(I,3)=.[illegible]
      T(I,4)=.[illegible]
      T(I,[illegible])=[illegible]
      T(I,7)=[illegible]
      T(I,[illegible])=[illegible]
      T(I,[illegible])=[illegible]
```

```
110   CONTINUE
      T(1,5)=1.0472
      T(2,5)=2.0944
      T(3,5)=3.1416
      T(4,5)=4.1888
      T(5,5)=5.236
      T(6,5)=0.
C
C
C     TYPE 2 IS 2 TARGETS IN SUBSYNCHRONOUS ORBITS
C
      DO 120 I=7,8
      T(I,1)=2.
      T(I,2)=3356.36
      T(I,3)=.01
      T(I,4)=.1854
      T(I,6)=4.9373
      T(I,7)=.02
      T(I,8)=-5.6
      T(I,9)=420.
120   CONTINUE
      T(7,5)=0.
      T(8,5)=.5236
C
C
C     TYPE 3 IS 3 TARGETS IN 500 NM CIRCULAR ORBITS
C
      DO 130 I=9,11
      T(I,1)=3.
      T(I,2)=7364.39
      T(I,3)=0.
      T(I,4)=1.1346
      T(I,6)=4.7124
      T(I,7)=.0012
      T(I,8)=-.7
      T(I,9)=77.
130   CONTINUE
      T(9,5)=.2618
      T(10,5)=2.3562
      T(11,5)=4.4506
C
C
C     TYPE 4 IS 3 TARGETS IN EQUATORIAL SYNCHRONOUS ORBITS
C
      DO 140 I=12,14
      T(I,1)=4.
      T(I,2)=17371.3
      T(I,3)=0.
      T(I,4)=0.
      T(I,6)=0.
      T(I,7)=.00263
      T(I,8)=-.25
      T(I,9)=[illegible]
140   CONTINUE
      T(12,5)=0.
      T(13,5)=[illegible]
      T(14,5)=[illegible]
```

```
C
C
C
C     INPUT TARGET TYPE SELECTIONS.  THESE SELECTIONS ARE INPUT ON SEPARATE CARDS
C     AS NUMBERS 1. THRU 4.. IN ANY ORDER OR COMBINATION, ENDING WITH A 99.
C
      DO 145 I=1,4
      D(I)=0.
  145 CONTINUE
      DO 50 I=1,4
      READ*,DEL
      IF(DEL.EQ.99.)GO TO 60
      IF(DEL.EQ.1.)D(1)=1.
      IF(DEL.EQ.2.)D(2)=2.
      IF(DEL.EQ.3.)D(3)=3.
      IF(DEL.EQ.4.)D(4)=4.
   50 CONTINUE
   60 CONTINUE
C
C     ELIMINATE NON-SELECTED TARGET DATA FROM "T" MATRIX
C
      IF(D(1).EQ.1.)GO TO 150
      DO 149 I=1,6
      T(I,1)=0.
  149 CONTINUE
  150 IF(D(2).EQ.2.)GO TO 155
      DO 154 I=7,[illegible]
      T(I,1)=0.
  154 CONTINUE
  155 IF(D(3).EQ.3.)GO TO 160
      DO 159 I=[illegible],11
      T(I,1)=0.
  159 CONTINUE
  160 IF(D(4).EQ.4.)GO TO 165
      DO 164 I=1[illegible],14
      T(I,1)=0.
  164 CONTINUE
  165 CONTINUE
C
C
C
C     ******************************************************
C     [illegible]
C
C     [illegible]
C
C     A CARD [illegible] INPUT [illegible] TYPE SELECTED.
C
C     [illegible]
C     [illegible]
C
C     [illegible]
C     [illegible]
C
C        [illegible]
C        [illegible]
C        [illegible]
```

```
C          NOTE...    THIS MUST BE THE SAME FOR ALL TARGET TYPES SELECTED.
C          PRITYP...TARGET TYPE PRIORITY    (DEFAULT 1.)    (1. TO 1000.)
C
C     ZERO THE MISSION MATRIX.
C
      DO 175 I=1,4
      DO 174 J=1,4
      MISSION(I,J)=0.
 174  CONTINUE
 175  CONTINUE
C
C
C
      IF(T(1,1).EQ.0.)GO TO 200
      READ*,(MISSION(1,IM),IM=1,4)
      IF(MISSION(1,2).EQ.0.)MISSION(1,2)=.8
      IF(MISSION(1,4).EQ.0.)MISSION(1,4)=1.
 200  IF(T(2,1).EQ.0.)GO TO 210
      READ*,(MISSION(2,IM),IM=1,4)
      IF(MISSION(2,2).EQ.0.)MISSION(2,2)=.8
      IF(MISSION(2,4).EQ.0.)MISSION(2,4)=1.
 210  IF(T(3,1).EQ.0.)GO TO 220
      READ*,(MISSION(3,IM),IM=1,4)
      IF(MISSION(3,2).EQ.0.)MISSION(3,2)=.8
      IF(MISSION(3,4).EQ.0.)MISSION(3,4)=1.
 220  IF(T(4,1).EQ.0.)GO TO 230
      READ*,(MISSION(4,IM),IM=1,4)
      IF(MISSION(4,2).EQ.0.)MISSION(4,2)=.8
      IF(MISSION(4,4).EQ.0.)MISSION(4,4)=1.
 230  CONTINUE
C
C     ****************************************************
C
C     BATTLE MANAGEMENT DATA INPUT
C
C     SELECTION OF ONE OR BOTH "SORTING METHODS" IS ALLOWED, ALTHOUGH
C     THE USER MAY SELECT NEITHER.
C
C     DEFAULTS ARE ACCEPTED BY ENTERING A "0." WHERE ALLOWED.
C     ONE FREE  FORMATTED CARD IS REQUIRED FOR EACH TARGET TYPE SELECTED,
C     WITH THE VARIABLE ORDER ON EACH CARD AS FOLLOWS....
C
C        TYPE.....TARGET TYPE (1.,2.,3., OR 4.)   (MANDATORY)
C        PRIFIR...FIRING PRIORITIES  (1.,2.,3., OR 4.)  (4., THE LOWEST)
C        IPRIME..SORTING BY IRRADIATION TIME  (1. OR 2.)  (DEFAULT 2.)
C
C     ZERO OUT THE TACTIC MATRIX.
C
      DO 223 I=1,4
      DO 222 J=1,4
      TACTIC(I,J)=0.
 222  CONTINUE
 223  CONTINUE
C
      IF(T(1,1).NE.0.)READ*,(TACTIC(1,II),II=1,3)
      IF(T(2,1).NE.0.)READ*,(TACTIC(2,II),II=1,3)
      IF(T(3,1).NE.0.)READ*,(TACTIC(3,II),II=1,3)
```

```
      IF(T(12,1).NE.0.)READ*,(TACTIC(4,II),II=1,3)
      DO 250 I=1,4
      IF(TACTIC(1,2).EQ.0.)TACTIC(1,2)=4.
      IF(TACTIC(2,2).EQ.0.)TACTIC(2,2)=4.
      IF(TACTIC(3,2).EQ.0.)TACTIC(3,2)=4.
      IF(TACTIC(4,2).EQ.0.)TACTIC(4,2)=4.
250   CONTINUE
C
C
C   THIS ENDS THE INPUT SECTION OF HELBASE.
C
C   ***********************************************
C
C   ZERO THE SUMEFF MATRIX.
C
      DO 337 I=1,5
      DO 339 J=1,1650
      SUMEFF(I,J)=0.
339   CONTINUE
337   CONTINUE
C
C
C   ZERO THE HELSEL MATRIX.
C
      DO 342 I=1,50
      DO 341 J=1,6
      HELSEL(I,J)=0.
341   CONTINUE
342   CONTINUE
C
C   ZERO THE TAROPP MATRIX.
C
      DO 338 I=1,14
      TAROPP(I)=0.
338   CONTINUE
C
C*****************************************************
C
C   THE FOLLOWING COMMANDS ARE USED AS A VALIDATION OF PROPER INPUTS
C
      PRINT*,"**************************************************"
      PRINT*,"**************************************************"
      PRINT*," "
      PRINT*,"***** WEAPON TYPES *****"
      PRINT*," "
      DO 300 I=1,NOWT
      PRINT*,"*** WEAPON TYPE ",I," ***"
      PRINT*," "
      PRINT*,"WAVELENGTH..................... ",WEAPON(1,I)," [illegible]"
      PRINT*,"BEAM POWER..................... ",WEAPON(2,I)," [illegible]"
      PRINT*,"[illegible]..................... ",WEAPON(3,I)," [illegible]"
      PRINT*,"MAXIMUM FIRING CYCLES.......... ",WEAPON(4,I)," [illegible]"
      PRINT*,"MAXIMUM [illegible] CYCLE ",WEAPON(5,I)," [illegible]"
      PRINT*,"[illegible]..................... ",WEAPON(6,I)," [illegible]"
      PRINT*,"[illegible]..................... ",WEAPON(7,I)," [illegible]"
      PRINT*,"[illegible]..................... ",[illegible](8,I)
      PRINT*,"[illegible]..................... ",[illegible]
```

```
C"
      PRINT*,"ABSORPTION COEFFICIENT....... ",WEAPON(11,I)," KILOMETERS
C EXP - 1"
      PRINT*," "
      PRINT*," "
  300 CONTINUE
      PRINT*," "
      PRINT*,"**************************************************"
      PRINT*,"**************************************************"
      PRINT*," "
      PRINT*," "
      PRINT*,"****** TARGET TYPES SELECTED ******"
      PRINT*," "
      PRINT*," "
      DO 310 I=1,14
      IF(T(I,1).EQ.0.)GO TO 310
      PRINT*," "
      PRINT*,"** TARGET TYPE ",T(I,1),", TARGET NUMBER ",I," **"
      PRINT*," "
      PRINT*,"SEMI/MAJOR AXIS............. ",T(I,2)," KILOMETERS"
      PRINT*,"ECCENTRICITY................ ",T(I,3)
      PRINT*,"INCLINATION................. ",T(I,4)," RADIANS"
      PRINT*,"LONGITUDE OF ASCENDING NODE ",T(I,5)," RADIANS"
      PRINT*,"ARGUMENT OF PERIGEE....... ",T(I,6)," RADIANS"
      PRINT*," "
  310 CONTINUE
      PRINT*," "
      PRINT*,"**************************************************"
      PRINT*,"**************************************************"
      PRINT*," "
      PRINT*," "
      PRINT*,"***** MISSION DATA *****"
      PRINT*," "
      PRINT*," "
      DO 320 I=1,4
      IF((I.EQ.1).AND.(T(1,1).EQ.0.))GO TO 320
      IF((I.EQ.2).AND.(T(2,1).EQ.0.))GO TO 320
      IF((I.EQ.3).AND.(T(9,1).EQ.0.))GO TO 320
      IF((I.EQ.4).AND.(T(10,1).EQ.0.))GO TO 320
      PRINT*,"** TARGET TYPE ",MISSION(I,1),"**"
      PRINT*," "
      PRINT*,"TARGET TYPE DURATION PERCENTAGE ",MISSION(I,2)
      PRINT*,"TARGET SYSTEM DURATION TIME .... ",MISSION(I,3)," MINUTES"
      PRINT*,"TARGET TYPE PRIORITY........... ",MISSION(I,4)
      PRINT*," "
  320 CONTINUE
      PRINT*," "
      PRINT*,"**************************************************"
      PRINT*,"**************************************************"
      PRINT*," "
      PRINT*," "
      PRINT*,"***** BATTLE MANAGEMENT DATA *****"
      PRINT*," "
      DO 330 I=1,4
      IF((I.EQ.1).AND.(T(1,1).EQ.0.))GO TO 330
      IF((I.EQ.2).AND.(T(2,1).EQ.0.))GO TO 330
      IF((I.EQ.3).AND.(T(9,1).EQ.0.))GO TO 330
```

```
      IF((I.EQ.4).AND.(T(1,1).EQ.0.))GO TO 330
      PRINT*,"** TARGET TYPE ",TACTIC(I,1),"**"
      PRINT*," "
      PRINT*,"FIRING PRIORITY.......... ",TACTIC(I,2)
      PRINT*,"SORT BY IRRADIATION TIME ",TACTIC(I,3)
      PRINT*,"                           (0. FOR NO, 1. FOR YES)"
      PRINT*," "
330   CONTINUE
      PRINT*," "
      PRINT*,"**************************************************"
      PRINT*,"**************************************************"
      PRINT*," "
      PRINT*," "
C
C   TRANSFORM HEL POWER INPUT TO INTENSITY- (WATTS/METER SQ.)
C
      WEAPON(2,I)=WEAPON(2,I)/(ACOS(-1.)*WEAPON(3,I)**2.)
C
C
C   CALL SPHERE FOR EACH WEAPON TYPE.
C
      DO 340 I=1,5
      IF(WEAPON(1,I).EQ.0.) GO TO 340
      R=WEAPON(1,I)*6372.165
      RC=I
      CALL SPHERE(R,RC,X,Y,Z,TH,PHI)
340   CONTINUE
C
      PRINT*,"   ",RC,"  SPHERES OF OPERATION HAVE BEEN DEFINED."
      PRINT*," "
      PRINT*," "
      ENUMSI=0.
C
      SCOUNT=1.
349   CALL SIG[illegible]ISSION,[illegible]T,XT,YT,ZT,WEAPON,X,Y,Z,SUMEFF,WEL[illegible],TARORD)
      ENUMSI=ENUMSI+1.
C
C   PRINT SIGMA RESULTS FOR VALIDATION.
C
      DO 350 II=1,2
      PRINT*,"******************************************"
      PRINT*," "
      PRINT*,"   SUMEFF VALUES FOR WEAPON TYPE ",II
      PRINT*," "
      DO 351 I=1,165
      JJ=10*I
      JJJ=JJ-9
      PRINT*," VALUES ",JJJ,(SUMEFF(II,J),J=JJJ,JJ)
351   CONTINUE
350   CONTINUE
C
C   AVERAGE THE VALUES IN THE SUMEFF MATRIX BY DIVIDING EACH VALUE BY THE
C   NUMBER OF TIMES SIGMA HAS BEEN CALLED.
C
      [illegible]
      [illegible]
      SU[illegible](I,J)=[illegible](I,J)/SCO[illegible]
```

```
399   CONTINUE
400   CONTINUE
C
C     TEST TO DETERMINE WHETHER SIGN HAS BEEN CALLED ENOUGH TIMES TO
C     SATISFY CONFIDENCE INTERVAL REQUIREMENTS.
C
C*****************************
      IF([illegible]) GO TO 411
C
C     MULTIPLY EACH VALUE OF SUMEFF BY SCOUNT.
C
      DO 410 I=1,5
      DO 410 J=1,150
      SUMEFF(I,J)=SUMEFF(I,J)*SCOUNT
410   CONTINUE
411   CONTINUE
      SCOUNT=SCOUNT+1.
      GO TO 359
411   CONTINUE
C
C     SO SUMEFF NOW CONTAINS VALUES OF THE AVERAGE SIGHTING EFFICIENCY WITHIN
C     A PRESCRIBED CONFIDENCE INTERVAL.
C
C     ****************************************************************
C     ****************************************************************
C     ****************************************************************
C
C     THIS SECTION IS THE "MODEL MAXIMIZER"
C
C     [illegible] PLACE THE FIRST (OR NEXT) WEAPON IN
C     [illegible] LATITUDE, AND TO DETERMINE [illegible] THE
C     [illegible] SYSTEM [illegible] TO SATISFY THE MISSION
C     [illegible]
C*******************************************************************
C     PLACE [illegible] "MOST EFFECTIVE" [illegible] OR LATITUDE.
C
C     [illegible] POSSIBILITIES FOR EACH WEAPON TYPE
C     [illegible]
C
C     [illegible] POSSIBILITIES FOR EACH WEAPON
C     [illegible]
C
[illegible]
C
C     [illegible] MATRIX [illegible] MATRIX.
C
[illegible]
```

```
C       THE ATTRIBUTE OF EFFICIENCY USED IS THE "PATH AVERAGE TARGET SYSTEM
C        SIGHTING EFFICIENCY", PTHEFF.
C
C
        PTHEFF=0.
        DO 415  J=1,72
        PTHEFF=PTHEFF+SUMEFF(I,J)
  415   CONTINUE
        PATH(I,1)=PTHEFF/72.
C
        PTHEFF=0.
        DO 416  J=73,144
        PTHEFF=PTHEFF+SUMEFF(I,J)
  416   CONTINUE
        PATH(I,2)=PTHEFF/72.
C
        PTHEFF=0.
        DO 417  J=145,215
        PTHEFF=PTHEFF+SUMEFF(I,J)
  417   CONTINUE
        PATH(I,3)=PTHEFF/71.
C
        PTHEFF=0.
        DO 418  J=216,286
        PTHEFF=PTHEFF+SUMEFF(I,J)
  418   CONTINUE
        PATH(I,4)=PTHEFF/71.
C
        PTHEFF=0.
        DO 419  J=286,353
        PTHEFF=PTHEFF+SUMEFF(I,J)
  419   CONTINUE
        PATH(I,5)=PTHEFF/66.
C
        PTHEFF=0.
        DO 420  J=354,419
        PTHEFF=PTHEFF+SUMEFF(I,J)
  420   CONTINUE
        PATH(I,6)=PTHEFF/66.
C
        PTHEFF=0.
        DO 421  J=420,48[illegible]
        PTHEFF=PTHEFF+SUMEFF(I,J)
  421   CONTINUE
        PATH(I,7)=PTHEFF/62.
C
        PTHEFF=0.
        DO 422  J=[illegible]31,5[illegible]9
        PTHEFF=PTHEFF+SUMEFF(I,J)
  422   CONTINUE
        PATH(I,8)=PTHEFF/89.
C
        PTHEFF=0.
        DO 423  J=[illegible],606
        PTHEFF=PTHEFF+SUMEFF(I,J)
  423   CONTINUE
        PATH(I,9)=PTHEFF/[illegible].
```

```
C
      PTHEFF=0.
      DO 424 J=595,645
      PTHEFF=PTHEFF+SUMEFF(I,J)
  424 CONTINUE
      PATH(I,10)=PTHEFF/51.
C
      PTHEFF=0.
      DO 425 J=646,691
      PTHEFF=PTHEFF+SUMEFF(I,J)
  425 CONTINUE
      PATH(I,11)=PTHEFF/46.
C
      PTHEFF=0.
      DO 426 J=692,732
      PTHEFF=PTHEFF+SUMEFF(I,J)
  426 CONTINUE
      PATH(I,12)=PTHEFF/41.
C
      PTHEFF=0.
      DO 427 J=733,768
      PTHEFF=PTHEFF+SUMEFF(I,J)
  427 CONTINUE
      PATH(I,13)=PTHEFF/36.
C
      PTHEFF=0.
      DO 428 J=769,799
      PTHEFF=PTHEFF+SUMEFF(I,J)
  428 CONTINUE
      PATH(I,14)=PTHEFF/31.
C
      PTHEFF=0.
      DO 429 J=[illegible],823
      PTHEFF=PTHEFF+SUMEFF(I,J)
  429 CONTINUE
      PATH(I,15)=PTHEFF/25.
C
      PTHEFF=0.
      DO 430 J=824,842
      PTHEFF=PTHEFF+SUMEFF(I,J)
  430 CONTINUE
      PATH(I,16)=PTHEFF/19.
C
      PTHEFF=0.
      DO 431 J=843,854
      PTHEFF=PTHEFF+SUMEFF(I,J)
  431 CONTINUE
      PATH(I,17)=PTHEFF/12.
C
      PTHEFF=0.
      DO 432 J=[illegible]
      PTHEFF=PTHEFF+SUMEFF(I,J)
  432 CONTINUE
      PATH(I,[illegible])=PTHEFF/[illegible].
C
      PTHEFF=[illegible](I,861)
      PATH(I,[illegible]
```

```
C
      PTHEFF=0.
      DO 433 J=862,933
      PTHEFF=PTHEFF+SUMEFF(I,J)
433   CONTINUE
      PATH(I,20)=PTHEFF/72.
C
      PTHEFF=0.
      DO 434 J=934,1004
      PTHEFF=PTHEFF+SUMEFF(I,J)
434   CONTINUE
      PATH(I,21)=PTHEFF/71.
C
      PTHEFF=0.
      DO 435 J=1005,1074
      PTHEFF=PTHEFF+SUMEFF(I,J)
435   CONTINUE
      PATH(I,22)=PTHEFF/70.
C
      PTHEFF=0.
      DO 436 J=1075,1142
      PTHEFF=PTHEFF+SUMEFF(I,J)
436   CONTINUE
      PATH(I,23)=PTHEFF/68.
C
      PTHEFF=0.
      DO 437 J=1143,1207
      PTHEFF=PTHEFF+SUMEFF(I,J)
437   CONTINUE
      PATH(I,24)=PTHEFF/65.
C
      PTHEFF=0.
      DO 438 J=1208,1269
      PTHEFF=PTHEFF+SUMEFF(I,J)
438   CONTINUE
      PATH(I,25)=PTHEFF/62.
C
      PTHEFF=0.
      DO 439 J=1270,1328
      PTHEFF=PTHEFF+SUMEFF(I,J)
439   CONTINUE
      PATH(I,26)=PTHEFF/59.
C
      PTHEFF=0.
      DO 440 J=1329,1383
      PTHEFF=PTHEFF+SUMEFF(I,J)
440   CONTINUE
      PATH(I,27)=PTHEFF/55.
C
      PTHEFF=0.
      DO 441 J=1384,1434
      PTHEFF=PTHEFF+SUMEFF(I,J)
441   CONTINUE
      PATH(I,28)=PTHEFF/51.
C
      PTHEFF=0.
      DO 442 J=1435,[illegible]
```

```
      PTHEFF=PTHEFF+SUMEFF(I,J)
  442 CONTINUE
      PATH(I,29)=PTHEFF/46.
C
      PTHEFF=0.
      DO 443 J=1481,1521
      PTHEFF=PTHEFF+SUMEFF(I,J)
  443 CONTINUE
      PATH(I,30)=PTHEFF/41.
      PTHEFF=0.
      DO 444 J=1522,1557
      PTHEFF=PTHEFF+SUMEFF(I,J)
  444 CONTINUE
      PATH(I,31)=PTHEFF/36.
C
      PTHEFF=0.
      DO 445 J=1558,1597
      PTHEFF=PTHEFF+SUMEFF(I,J)
  445 CONTINUE
      PATH(I,32)=PTHEFF/39.
C
      PTHEFF=0.
      DO 446 J=1598,1612
      PTHEFF=PTHEFF+SUMEFF(I,J)
  446 CONTINUE
      PATH(I,33)=PTHEFF/15.
C
      PTHEFF=0.
      DO 447 J=1613,1631
      PTHEFF=PTHEFF+SUMEFF(I,J)
  447 CONTINUE
      PATH(I,34)=PTHEFF/19.
C
      PTHEFF=0.
      DO 448 J=1632,1643
      PTHEFF=PTHEFF+SUMEFF(I,J)
  448 CONTINUE
      PATH(I,35)=PTHEFF/12.
C
      PTHEFF=0.
      DO 449 J=1644,1649
      PTHEFF=PTHEFF+SUMEFF(I,J)
  449 CONTINUE
      PATH(I,36)=PTHEFF/6.
C
      PTHEFF=SUMEFF(I,1650)
      PATH(I,37)=PTHEFF
C
C   THIS COMPLETES THE FINDING OF THE "PATH EFFICIENCIES" FOR EACH
C      [illegible] OF MODES 1, AND 2.
C
C
      IF(HEAPOA(9,T).LT.3.)GO TO 500
  450 CONTINUE
C
C   FOLLOWING [illegible] OTHER VALUES IN THE PATH MATRIX FOR MODE 3 [illegible].
C
```

```
C     VALUES OF THE "AVERAGE TARGET SYSTEM SIGHTING EFFICIENCY" ARE STORED
C     I IS THE WEAPON TYPE AND J IS THE POINT NUMBER ON THE SPHERE OF OPERATIONS.
C
C
C
C     THE ORBITAL PATHS HAVE BEEN SEPARATELY CALCULATED AND STORED IN TERMS
C        OF THE SPHERE OF OPERATIONS POINTS NEEDED TO MAKE UP THE PATH OF THE
C        ORBIT.   THE POINTS ARE STORED IN MATRIX ORBITS(IORBIT,JPOINT).
C        EACH OF THE 925 POSSIBLE ORBITS IS REPRESENTED BY 36
C        VALUES OF THE "AVERAGE TARGET SYSTEM SIGHTING EFFICIENCY".
C
C
C     CALCULATE "PATH AVERAGE TARGET SYSTEM SIGHTING EFFICIENCY" FOR THE
C        IORBIT PATH.
C
      DO 495 IORBIT=1,925
      PTHEFF=0.
      DO 490 JPOINT=1,36
C     AS FOR THE LATITUDINAL PATHS, PTHEFF IS USED TO ADD AND THEN AVERAGE THESE
C              VALUES TO THE "PATH AVERAGE TARGET SYSTEM SIGHTING EFFICIENCIES".
C
      PTHEFF=PTHEFF+SUMEFF(I,ORBITS(IORBIT,JPOINT))
 490  CONTINUE
      PTHEFF=PTHEFF/36.
      PATH(I,IORBIT)=PTHEFF
 495  CONTINUE
 500  CONTINUE
C
C     THE PATH(5 X 925) MATRIX NOW CONTAINS "PATH SIGHTING EFFICIENCY " VALUES
C     FOR ALL POSSIBLE PATHS OF ALL WEAPON TYPES.
C
C     MODES 1 AND 2 WEAPON TYPES WILL ONLY HAVE 37 VALUES IN A ROW.
C     MODE 3 WEAPON TYPES WILL HAVE 925 VALUES IN A ROW.
C
C
C     CHOOSE THE PATH WITH THE MAXIMUM EFFICIENCY.
C
C     LET IMAX BE THE WEAPON TYPE (INDEXED), AND JMAX THE LATITUDE OR ORBIT NO.
C
      XMAX=0.
      DO 540 I=1,5
      DO 530 J=1,925
      IF(PATH(I,J).GT.XMAX)IMAX=I
      IF(PATH(I,J).GT.XMAX)JMAX=J
      IF(PATH(I,J).GT.XMAX)XMAX=PATH(I,J)
 530  CONTINUE
 540  CONTINUE
C
C     SO THE WEAPON SELECTED BY OPTIMIZE TO BE ADDED TO THE WEAPON SYSTEM IS
C     WEAPON IMAX IN LATITUDE OR ORBIT JMAX.
C
C***********************************************************************
C
C     [illegible]
C     [illegible] WEAPON SYSTEM.
C
C     [illegible]
```

```
C
      IC=0
      DO 600 I=1,50
      IF(HELSEL(I,1).NE.0.)IC=IC+1
600   CONTINUE
C
C   HELSEL(IC,1) IS THE WEAPON TYPE (REAL).
C
      IC=IC+1
      X99=IMAX
      HELSEL(IC,1)=X99
C
C
C   HELSEL(IC,2) IS THE ORBITAL RADIUS (MODE 3), OR THE SPHERICAL COORDINATE
C   THETA (MODES 1 OR 2).
C
      IF(WEAPON(3,IMAX).EQ.3.)HELSEL(IC,2)=WEAPON(1[illegible],IMAX)+6378.145
      IF(WEAPON(3,IMAX).LT.3.)HELSEL(IC,2)=TH(JMAX)
C
C
C   HELSEL(IC,3) IS THE ORBITAL ECCENTRICITY, AND IS ZERO.
C
C
C   HELSEL(IC,4) IS THE ORBITAL INCLINATION, AND IS EQUAL TO THE SPHERICAL
C   ANGLE THETA OF THE ORBITAL UNIT MOMENTUM VECTOR.
C
C
C   IF THE ORBIT NUMBER IS 37 THROUGH 325, THE CORRESPONDING UNIT ANGULAR
C   MOMENTUM VECTOR IS 73 THROUGH 865.
C
      IF(JMAX.GT.37)JMAX=J[illegible]+36
C
      IF((JMAX.GE.1.).AND.(JMAX.LE.72))HELSEL(IC,4)=TH(1)
      IF((JMAX.GE.73).AND.(JMAX.LE.144))HELSEL(IC,4)=TH(2)
      IF((JMAX.GE.145).AND.(JMAX.LE.21[illegible]))HELSEL(IC,4)=TH(3)
      IF((JMAX.GE.216).AND.(JMAX.LE.2[illegible]))HELSEL(IC,4)=TH(4)
      IF((JMAX.GE.2[illegible]).AND.(JMAX.LE.35[illegible]))HELSEL(IC,4)=TH(5)
      IF((JMAX.GE.354).AND.(JMAX.LE.41[illegible]))HELSEL(IC,4)=TH(6)
      IF((JMAX.GE.413).AND.(JMAX.LE.4[illegible]))HELSEL(IC,4)=TH(7)
      IF((JMAX.GE.481).AND.(JMAX.LE.53[illegible]))HELSEL(IC,4)=TH(8)
      IF((JMAX.GE.54[illegible]).AND.(JMAX.LE.[illegible]))HELSEL(IC,4)=TH(9)
      IF((JMAX.GE.[illegible]).AND.(JMAX.LE.[illegible]))HELSEL(IC,4)=TH(10)
      IF((JMAX.GE.64[illegible]).AND.(JMAX.LE.6[illegible]))HELSEL(IC,4)=TH(11)
      IF((JMAX.GE.692).AND.(JMAX.LE.[illegible]))HELSEL(IC,4)=TH(12)
      IF((JMAX.GE.73[illegible]).AND.(JMAX.LE.7[illegible]))HELSEL(IC,4)=TH(13)
      IF((JMAX.GE.7[illegible]).AND.(JMAX.LE.7[illegible]))HELSEL(IC,4)=TH(14)
      IF((JMAX.GE.79[illegible]).AND.(JMAX.LE.[illegible]))HELSEL(IC,4)=TH(15)
      IF((JMAX.GE.824).AND.(JMAX.LE.[illegible]))HELSEL(IC,4)=TH(16)
      IF((JMAX.GE.[illegible]).AND.(JMAX.LE.[illegible]))HELSEL(IC,4)=TH(17)
      IF((JMAX.GE.[illegible]).AND.(JMAX.LE.[illegible]))HELSEL(IC,4)=TH(18)
      IF(JMAX.GT.[illegible])HELSEL(IC,4)=0.
C
C
C    HELSEL(IC,5) IS THE [illegible] OF THE ASCENDING NODE.
C   THE ORBIT [illegible]
C   POINT THAT [illegible] A UNIT [illegible] OF [illegible]
C   THEREFORE, THE LONGITUDE OF THE ASCENDING NODE IS THE SPHERICAL
```

```
C     COORDINATE PHI OF THE UNIT MOMENTUM VECTOR PLUS PI/2.
C
      HELSEL(IC,5)=PHI(JMAX)+ACOS(-1.)/2.
C
C
C     HELSEL(IC,6) IS THE ARGUMENT OF PERIGEE, AND IS ZERO.
C
C     THIS COMPLETES THE STORAGE OF THE SELECTED WEAPON PARAMETERS IN HELSEL.
C
C*****************************************************************************
C
C     THE MATRIX SUMEFF HAS NOW SERVED ITS PURPOSE, AND IS ZEROED.
C
      DO 650 I=1,5
      DO 640 J=1,1550
      SUMEFF(I,J)=0.
  640 CONTINUE
  650 CONTINUE
C
      BCOUNT=0.
      SUCESA=0.
C     THIS SECTION OF SU MODEL OPTIMIZE RUNS BATTLE ENOUGH TIMES
C     TO DEVELOP A CONFIDENCE OF .9 THAT THE CURRENT WEAPON SYSTEM (WEAPONS
C     SELECTED BY OPTIMIZE AND STORED IN HELSEL) EITHER CAN OR CANNOT
C     MEET THE MISSION REQUIREMENTS SPECIFIED BY THE USER.
C
      ENUF=0.
  651 CALL BATTLE(TACTIC,MISSION,HELSEL,T,WEAPON,TARCPP,XT,YT,ZT,J9)
      ENUF=ENUF+1.
C
C     J9 IS THE NUMBER OF TARGETS NEGATED DURING THIS RUN OF BATTLE.
C     IF J9 IS 14 (TARGETS NOT SELECTED ARE CONSIDERED PREVIOUSLY NEGATED),
C     THE BATTLE WAS A SUCCESS.
C
      BC=BCOUNT+1.
      PRINT*,J9," TARGETS DESTROYED FOR BATTLE NO. ",BC
      SUCESS=0.
      IF(J9.EQ.14)SUCESS=1.
      SUCESA=SUCESA*BCOUNT
      SUCESA=SUCESA+SUCESS
      SUCESA=SUCESA/BC
C
C
C     IF THE MEAN OF "SUCCESS" CAN BE ESTIMATED WITHIN + OR - 10% OF ITS TRUE
C     VALUE WITH A CONFIDENCE OF .9, ENOUGH BATTLES HAVE BEEN RUN.
C
  659 CONTINUE
C
C     IF ENOUGH BATTLES HAVE NOT BEEN RUN TO GET A GOOD ESTIMATE OF THE MEAN,
C     CALL SIDEN TO LOOK AT THE TARGETS REMAINING AT THE END OF THIS BATTLE.
C
C     MULTIPLY THE SUMEFF VALUES BY BCOUNT.
C
      DO 660 I=1,5
      DO 670 J=1,1550
      SUMEFF(I,J)=SUMEFF(I,J)*BCOUNT
  670 CONTINUE
```

```
  650 CONTINUE
C
C    NOW CALL SIGEN TO ADD THE SIGHTINGS OF THE REMAINING TARGETS TO THE
C    MATRIX SUMEFF.
C
      CALL SIGEN(MISSION,I,XI,YI,ZI,WEAPON,X,Y,Z,SUMEFF,HELSEL,TARDEP)
C
C    THEN THE SUMEFF VALUES MUST BE AVERAGED.
C
      CCOUNT=CCOUNT+1.
      DO 670 I=1,5
      DO 669 J=1,1650
      SUMEFF(I,J)=SUMEFF(I,J)/CCOUNT
  669 CONTINUE
  670 CONTINUE
C**********************
C    TEST FOR SUCCESS MEAN.
      IF(ENUF.EQ.3.)GO TO 710
C
C***************************
C
C    AND FINALLY RUN ANOTHER BATTLE.
C
      GO TO 651
C
C
C
  710 CONTINUE
C
C    ENOUGH BATTLES HAVE BEEN RUN TO PROPERLY ESTIMATE THE MEAN OF SUCESS.
C    IF THE AVERAGE OF SUCESS IS .GE. TO .9, THE CURRENT WEAPON SYSTEM
C    MEETS THE MISSION REQUIREMENTS, AND THE WEAPON SYSTEM MAY BE OUTPUT.
C
      IF(SUCESA.GE..9)GO TO 1000
C
C    IF THE AVERAGE OF SUCESS IS .LT. .9, ANOTHER WEAPON IS NEEDED.
C    BEFORE ANOTHER WEAPON CAN BE PLACED BY OPTIMIZE, THE AVERAGE SIGHTING
C    EFFICIENCY VALUES IN SUMEFF MUST BE ESTIMATED WITHIN + OR - 1.% OF THE
C    TRUE MEANS WITH A CONFIDENCE OF .9.
C
C************************
C    TEST FOR MEAN.
      ENUFSI=1.
C**************************
C
C    IF ENOUGH CALLS OF SIGEN HAVE BEEN MADE, OPTIMIZE CAN PLACE THE NEXT WEAPON.
C
      IF(ENUFSI.EQ.1.)GO TO 410
C
C    IF ENOUGH CALLS OF SIGEN HAVE NOT BEEN MADE, RUN ANOTHER BATTLE.
C
      GO TO 651
 1000 CONTINUE
C
C    OUTPUT THE FINAL WEAPON SYSTEM THAT MEETS MISSION REQUIREMENTS.
C
      PRINT 8,** **
```

```
      PRINT*,"**********************************************"
      PRINT*," "
      PRINT*,"          ***** OUTPUT WEAPONS SELECTED *****"
      PRINT*," "
C
C   COUNT THE NUMBER OF WEAPONS SELECTED (LCOUNT).
      LCOUNT=0
      DO 1010 I=1,50
      IF(HELSEL(I,1).NE.0.)LCOUNT=LCOUNT+1
 1010 CONTINUE
C
C   MWEP IS THE INTEGER WEAPON TYPE.
C
      DO 1020 I=1,LCOUNT
      PRINT*,"   WEAPON SELECTION NUMBER ",I
      MWEP=HELSEL(I,1)
      PRINT*,"                  WEAPON TYPE ",MWEP
      PRINT*,"                  MODE NUMBER ",WEAPON(9,MWEP)
      IF(WEAPON(9,MWEP).LT.3.)PRINT*,"                  LATITUDE IS ",
     CHELSEL(I,2)
      IF(WEAPON(9,MWEP).EQ.3.)PRINT*,"                  ORBITAL RADIUS ",
     CHELSEL(I,3)
      IF(WEAPON(9,MWEP).EQ.3.)PRINT*,"                  ORBITAL INCLINATION
     CIS ",HELSEL(I,4)
      IF(WEAPON(9,MWEP).EQ.3.)PRINT*,"                  LONGITUDE OF ASCEND
     CING NODE IS ",HELSEL(I,5)
      PRINT*," "
      PRINT*," "
 1020 CONTINUE
      STOP
      END
```

```
      SUBROUTINE [illegible](R,NO,X,Y,Z,TH,PHI)
      DIMENSION X(1,1652),Y(1,1652),Z(1,1652),TH(37),PHI(1652)
      INTEGER RC
C
C  PROVIDES 3-D CARTESIAN COORDINATES OF ALL 1652 POINTS ON THE
C  SPHERE OF OPERATIONS FOR A SINGLE RADIUS
C   CALL STATEMENT MUST SPECIFY WHICH RADIUS AND ENUMERATOR IS TO BE USED
C
      TH(1)=1.5708
      TH(2)=1.4835
      TH(3)=1.4137
      TH(4)=1.3265
      TH(5)=1.2393
      TH(6)=1.1362
      TH(7)=1.0374
      TH(8)=.9696
      TH(9)=.8693
      TH(10)=.7871
      TH(11)=.6972
      TH(12)=.6059
      TH(13)=.5236
      TH(14)=.4293
      TH(15)=.3546
      TH(16)=.2571
      TH(17)=.1675
      TH(18)=.0934
      TH(19)=.0
      TH(20)=1.6581
      TH(21)=1.7376
      TH(22)=1.8371
      TH(23)=1.9257
      TH(24)=2.0156
      TH(25)=2.[illegible]41
      TH(26)=2.1411
      TH(27)=2.2723
      TH(28)=2.3544
      TH(29)=2.4493
      TH(30)=2.5263
      TH(31)=2.6193
      TH(32)=2.7113
      TH(33)=2.7871
      TH(34)=2.8763
      TH(35)=2.9741
      TH(36)=3.0582
      TH(37)=3.1415
C
C   POINTS 1 THRU 72
C
      XC=0.
      DO 1 I=1,72
      PHI(I)=XC*6.28[illegible]/72.
      CALL CARTE[illegible](R,NO,TH,PHI,1,1,X,Y,Z)
      XC=XC+1.
    1 CONTINUE
C
C   POINTS ON LATITUDE [illegible] 144) [illegible] (857 THRU [illegible]
C
```

```
      XC=0.
      DO 2 I=73,143
      PHI(I)=XC*6.28318/72.
      PHI(I+789)=PHI(I)
      CALL CART(R,RC,TH,PHI,I,2,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+789,20,X,Y,Z)
      XC=XC+1.
    2 CONTINUE
      PHI(144)=357.5*6.28318/360.
      CALL CART(R,RC,TH,PHI,144,2,X,Y,Z)
      PHI(933)=PHI(144)
      CALL CART(R,RC,TH,PHI,933,20,X,Y,Z)
C
C     POINTS ON LAT. 3(145 THRU 215) AND 21(934 THRU 1004)
C
      XC=0.
      DO 3 I=145,215
      PHI(I)=XC*6.28318/71.
      PHI(I+789)=PHI(I)
      CALL CART(R,RC,TH,PHI,I,3,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+789,21,X,Y,Z)
      XC=XC+1.
    3 CONTINUE
C
C     POINTS ON LAT. 4(216 THRU 285) AND 22(1005 THRU 1074)
C
      XC=0.
      DO 4 I=216,285
      PHI(I)=XC*6.28318/70.
      PHI(I+789)=PHI(I)
      CALL CART(R,RC,TH,PHI,I,4,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+789,22,X,Y,Z)
      XC=XC+1.
    4 CONTINUE
C
C     POINTS FOR LAT. 5(286 THRU 353) AND 23(1075 THRU 1142)
C
      XC=0.
      DO 5 I=286,353
      PHI(I)=XC*6.28318/68.
      PHI(I+789)=PHI(I)
      CALL CART(R,RC,TH,PHI,I,5,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+789,23,X,Y,Z)
      XC=XC+1.
    5 CONTINUE
C
C     POINTS FOR LAT. 6(354 THRU 413) AND 24(1143 THRU 1202)
C
      XC=0.
      DO 6 I=354,413
      PHI(I)=XC*6.28318/60.
      PHI(I+789)=PHI(I)
      CALL CART(R,RC,TH,PHI,I,6,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+789,24,X,Y,Z)
      XC=XC+1.
    6 CONTINUE
C
```

```
C     POINTS FOR LAT. 7(419 THRU 483) AND 25(1208 THRU 1269)
C
      XC=0.
      DO 7 I=419,483
      PHI(I)=XC*6.28318/65.
      PHI(I+789)=PHI(I)
      CALL CART(2,RC,TH,PHI,I,7,X,Y,Z)
      CALL CART(2,RC,TH,PHI,I+789,25,X,Y,Z)
      XC=XC+1.
    7 CONTINUE
C
C     POINTS FOR LAT. 8(484 THRU 539) AND 26(1273 THRU 1328)
C
      XC=0.
      DO 8 I=484,539
      PHI(I)=XC*6.28318/56.
      PHI(I+789)=PHI(I)
      CALL CART(2,RC,TH,PHI,I,8,X,Y,Z)
      CALL CART(2,RC,TH,PHI,I+789,26,X,Y,Z)
      XC=XC+1.
    8 CONTINUE
C
C     POINTS FOR LAT. 9(540 THRU 594) AND 27(1329 THRU 1383)
C
      XC=0.
      DO 9 I=540,594
      PHI(I)=XC*6.28318/55.
      PHI(I+789)=PHI(I)
      CALL CART(2,RC,TH,PHI,I,9,X,Y,Z)
      CALL CART(2,RC,TH,PHI,I+789,27,X,Y,Z)
      XC=XC+1.
    9 CONTINUE
C
C     POINTS FOR LAT. 10(595 THRU 645) AND 28(1384 THRU 1434)
C
      XC=0.
      DO 10 I=595,645
      PHI(I)=XC*6.28318/51.
      PHI(I+789)=PHI(I)
      CALL CART(2,RC,TH,PHI,I,10,X,Y,Z)
      CALL CART(2,RC,TH,PHI,I+789,28,X,Y,Z)
      XC=XC+1.
   10 CONTINUE
C
C     POINTS FOR LAT. 11(646 THRU 691) AND 29(1435 THRU 1480)
C
      XC=0.
      DO 11 I=646,691
      PHI(I)=XC*6.28318/46.
      PHI(I+789)=PHI(I)
      CALL CART(2,RC,TH,PHI,I,11,X,Y,Z)
      CALL CART(2,RC,TH,PHI,I+789,29,X,Y,Z)
      XC=XC+1.
   11 CONTINUE
C
C     POINTS FOR LAT. 12(692 THRU 732) AND 30(1481 THRU 1521)
C
```

```
      XC=0.
      DO 12 I=692,732
      PHI(I)=XC*6.28318/41.
      PHI(I+789)=PHI(I)
      CALL CART(R,XC,TH,PHI,I,12,X,Y,Z)
      CALL CART(R,XC,TH,PHI,I+789,31,X,Y,Z)
      XC=XC+1.
   12 CONTINUE
C
C   POINTS FOR LAT. 13(733 THRU 768) AND 31(1522 THRU 1557)
C
      XC=0.
      DO 13 I=733,768
      PHI(I)=XC*6.28318/36.
      PHI(I+789)=PHI(I)
      CALL CART(R,XC,TH,PHI,I,13,X,Y,Z)
      CALL CART(R,XC,TH,PHI,I+789,31,X,Y,Z)
      XC=XC+1.
   13 CONTINUE
C
C   POINTS FOR LAT. 14(769 THRU 798) AND 32(1558 THRU 1587)
C
      XC=0.
      DO 14 I=769,798
      PHI(I)=XC*6.28318/30.
      PHI(I+789)=PHI(I)
      CALL CART(R,XC,TH,PHI,I,14,X,Y,Z)
      CALL CART(R,XC,TH,PHI,I+789,32,X,Y,Z)
      XC=XC+1.
   14 CONTINUE
C
C   POINTS FOR LAT. 15(799 THRU 823) AND 33(1588 THRU 1612)
C
      XC=0.
      DO 15 I=799,823
      PHI(I)=XC*6.28318/25.
      PHI(I+789)=PHI(I)
      CALL CART(R,XC,TH,PHI,I,15,X,Y,Z)
      CALL CART(R,XC,TH,PHI,I+789,33,X,Y,Z)
      XC=XC+1.
   15 CONTINUE
C
C   POINTS FOR LAT. 16(824 THRU 842) AND 34(1613 THRU 1631)
C
      XC=0.
      DO 16 I=824,842
      PHI(I)=XC*6.28318/19.
      PHI(I+789)=PHI(I)
      CALL CART(R,XC,TH,PHI,I,16,X,Y,Z)
      CALL CART(R,XC,TH,PHI,I+789,34,X,Y,Z)
      XC=XC+1.
   16 CONTINUE
C
C   POINTS FOR LAT. 17(843 THRU [illegible]) AND 35(1632 THRU [illegible])
C
      XC=0.
      DO 17 I=843,[illegible]
```

```
      PHI(I)=XC*6.28313/12.
      PHI(I+789)=PHI(I)
      CALL CART(R,RC,TH,PHI,I,17,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+789,35,X,Y,Z)
      XC=XC+1.
   17 CONTINUE
C
C  POINTS FOR LAT. 18(855 THRU 860) AND 36(1644 THRU 1649)
C
      XC=1.
      DO 18 I=855,860
      PHI(I)=XC*6.28313/6.
      PHI(I+789)=PHI(I)
      CALL CART(R,RC,TH,PHI,I,18,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+789,35,X,Y,Z)
      XC=XC+1.
   18 CONTINUE
C
C  POINT FOR LAT. 19(861)
C
      PHI(861)=0.
      CALL CART(R,RC,TH,PHI,861,19,X,Y,Z)
C
C  POINT FOR LAT. 37(1650)
      PHI(1650)=6.28313
      CALL CART(R,RC,TH,PHI,1650,37,X,Y,Z)
      RETURN
      END
```

```
C
C
      SUBROUTINE CART(R,SC,TH,PHI,IX,JX,X,Y,Z)
      DIMENSION TH(37),PHI(1653),X(5,1653),Y(5,1653),Z(5,1653)
      INTEGER SC
      X(SC,IX)=R*SIN(TH(JX))*COS(PHI(IX))
      Y(SC,IX)=R*SIN(TH(JX))*SIN(PHI(IX))
      Z(SC,IX)=R*COS(TH(JX))
      RETURN
      END
```

```
      SUBROUTINE [illegible](MISSION,T,XT,YT,ZT,WEAPON,X,Y,Z,SUMEFF,
     C HELSEL,TARDPP)
      INTEGER WEAPNO,PTNO,TGTNO,PC,NOWT,TTYPE
      REAL [illegible],[illegible],LAM,[illegible],MISSION
      DIMENSION X(5,1650),Y(5,165[illegible]),Z(5,15[illegible]),T(14,1[illegible]),XT(14),
     CYT(14),ZT(14),WEAPON([illegible]),SUMEFF(5,[illegible]),HELSEL([illegible],5),
     C MISSION(4,4),TARDPP(14)
      COMMON E,XM
C
C     THE PURPOSE OF THIS SUB-MODEL IS TO GENERATE THE "TARGET SYSTEM
C     SIGHTING EFFICIENCY" VALUES FOR EACH POINT ON EACH SPHERE OF OPERATIONS
C     (STORED IN MATRIX SUMEFF)
C
C     IF THE FIRST WEAPON IS PLACED, P=1.
C
      P=0.
      J=0
      DO 15 I=1,[illegible]
      IF(HELSEL(I,1).NE.0.)J=J+1
   15 CONTINUE
      IF(J.NE.0)P=1.
      IF(P.EQ.1.)GO TO 93
      CALL TARGET(T,XT,YT,ZT)
   93 CONTINUE
C
C     COUNT THE NUMBER OF TARGETS SELECTED (OR SURVIVING).
C
      JT=0
      IF(P.EQ.1.) GO TO 10
      DO 5 I=1,14
      IF(T(I,1).NE.0.)JT=JT+1
    5 CONTINUE
      IF(P.EQ.0.)GO TO 8
   10 CONTINUE
      DO 9 I=1,14
      IF(TARDPP(I).NE.0.)JT=JT+1
    9 CONTINUE
    8 CONTINUE
      WEAPNO=0
C
C     WEAPNO= WEAPON TYPE NUMBER
C
   20 WEAPNO=WEAPNO+1
      IF([illegible](1,WEAPNO).EQ.0.) GO TO 60
      R=[illegible](10,WEAPNO)*6378.145
C
C
C     PTNO=POINT ON SPHERE OF OPERATIONS
C
      PTNO=0
   30 PTNO=PTNO+1
C
C     [illegible]
C
      TGTNO=0
   40 TGTNO=TGTNO+1
C
```

```
C     IF THE TARGET WAS NOT SELECTED BY THE USER, DONT CALL SIGHT.
C
      IF(TGTNO.EQ.1)GO TO 50
      IF(T(TGTNO,1).EQ.0.)GO TO 40
C
C     IF THE CALL OF STORM IS FROM OPTIMIZE AFTER A BATTLE, THE TARGET
C     MUST HAVE SURVIVED THE BATTLE TO BE LOOKED AT HERE.
C
      IF((P.EQ.1.).AND.(TARGEP(TGTNO).EQ.3.))GO TO 40
      CALL SIGHT(WEAPNO,TGTNO,WEAPON,IPSTCN,F,X(WEAPNO,PTNO),
     C Y(WEAPNO,PTNO),Z(WEAPNO,PTNO),XT(TGTNO),YT(TGTNO),ZT(TGTNO),S)
      SUMEFF(WEAPNO,PTNO)=SUMEFF(WEAPNO,PTNO)+S
      GO TO 40
 50   IF((PTNO+1).EQ.1651)GO TO 60
      GO TO 30
 60   IF(WEAPNO.EQ.5)GO TO 70
      GO TO 20
 70   CONTINUE
 100  RETURN
      END
```

```
      SUBROUTINE TARGET (T,XT,YT,ZT)
      DIMENSION T(14,13),XT(14),YT(14),ZT(14)
      EXTERNAL F
      COMMON E,XM
C
C   GENERATES CARTESIAN COORDINATES FOR RANDOM POSITIONS OF ALL SELECTED
C   TARGETS
C
      PI=ACOS(-1.)
      TWOPI=2.*PI
      DO 100 I=1,14
C
C   CHECK WHETHER TARGET HAS BEEN SELECTED
C
      IF(T(I,1).EQ.0.)GO TO 100
C
C   FOLLOWING RANDOM SELECTION OF THE TRUE ANOMALY (ETA) IS DONE IN 3 STEPS..
C     STEP 1- A MEAN ANOMALY (XM) IS DRAWN FROM A UNIFORM (0,2PI) DIST?.
C
      RN=RANF(DUM)
      XM=RN*TWOPI
C
C   FOR TARGET TYPE 2, THE MEAN ANOMALIES ARE SEPARATED BY 180 DEGREES.
C
      IF(I.EQ.?)XM=T(7,1)+PI
C
C   FOR TARGET TYPE 4, THE MEAN ANOMALIES ARE SEPARATED BY 120 DEGREES.
C
      IF(I.EQ.13)XM=T(12,1)+TWOPI/3.
      IF(I.EQ.14)XM=T(13,1)+TWOPI/3.
      T(I,1)=XM
C
C     STEP 2- THIS MEAN ANOMALY XM IS THEN TRANSFORMED TO THE ECCENTRIC
C     ANOMALY [illegible] BY A ROOT SOLUTION OF THE TRANSCENDENTAL EQUATION.
C
C
C   IF THE TARGET HAS ECCENTRICITY OF 0, THE MEAN ANOMALY, ECCENTRIC ANOMALY
C   AND TRUE ANOMALY ARE THE SAME.
C
      IF(T(I,3).EQ.0.)ETA=XM
      IF(T(I,3).EQ.0.)GO TO [illegible]
C
C   ROOT SOLUTION SEPARATOR (TO GUARANTEE DIFFERENT SIGNS TO Z POINT) IS TWICE
C     THE ORBITAL ECCENTRICITY.
C
      E=T(I,3)
      A=XM-2.*E
      B=XM+2.*E
      CALL Z[illegible](F,[illegible])
      EA=[illegible]
C
C     STEP 3- THE TRUE ANOMALY ETA IS THEN CALCULATED USING THE ECCENTRIC
C     ANOMALY EA.
C
      ETA=[illegible]
 [illegible] CONTINUE
C
```

```
C     CALCULATE R, THETA, AND PHI FROM ORBITAL PARAMETERS
C     AND RANDOM TRUE ANOMALY
C
      R=T(I,2)*(1.-T(I,3)**2.)/(1.+T(I,3)*COS(ETA))
      THETA=(PI/2.)-(T(I,4)*SIN(T(I,6)+ETA))
      PHIS=T(I,6)+T(I,5)+ETA
C
C     CALCULATE CARTESIAN COORDINATES
C
      XT(I)=R*SIN(THETA)*COS(PHIS)
      YT(I)=R*SIN(THETA)*SIN(PHIS)
      ZT(I)=R*COS(THETA)
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SIGHT(WEAPNO,TGTNO,WEAPON,MISSION,T,XS,YS,ZS,XIS,YIS,
     C ZIS,S)
      REAL MODENO,IO,IOT,LAM,NSIG,MISSION
      INTEGER TGTNO,WEAPNO,TTYPE
      DIMENSION T(14,10),WEAPON(11,6),MISSION(4,4)
C
C    *** THE FOLLOWING ARE INPUT VARIABLES TO SIGHT***
C
C    WEAPNO= CURRENT WEAPON NUMBER  (INTEGER)
C    T= TARGET CHARACTERISTICS MATRIX
C    TGTNO= CURRENT TARGET NUMBER  (INTEGER)
C    XS,YS, AND ZS ARE COORDINATES OF WEAPON POINT
C    XIS,YIS, AND ZIS ARE COORDINATES OF TARGET
C    DELTIM= MAXIMUM FIRING TIME ALLOWED
C    RANMAX= MAXIMUM RANGE ALLOWED
C
C    *** THE OUTPUT IS  S/T,  THE TARGET SIGHTING EFFICIENCY FOR THIS
C    ONE-ON-ONE,  ONE-TIME SIGHTING ATTEMPT***
C    SUBROUTINE "SIGHT" IS USED BY BOTH "SCREEN" AND "BATTLE"
C
C    "SIGHT" IS PROVIDED A WEAPON AND ITS INSTANTANEOUS POSITION, AND
C    THE POSITION OF A SPECIFIC TARGET
C
C
C    THE PURPOSE OF "SIGHT" IS TO DETERMINE WHETHER THAT TARGET COULD
C    BE NEGATED BY THAT WEAPON WITH THE GEOMETRY IMPLIED
C
C    COMPUTE VECTOR XL, YL, ZL FROM THE WEAPON (OR POINT) TO THE TARGET.
C
      XL=XIS-XS
      YL=YIS-YS
      ZL=ZIS-ZS
C
C    COMPUTE RANGE FROM WEAPON OR POINT TO TARGET
C
      RANGE=SQRT(XL**2.+YL**2.+ZL**2.)
C
C    COMPUTE DIRECTION COSINES OF VECTOR FROM WEAPON OR POINT
C    TO TARGET
C
      XLCOS=XL/RANGE
      YLCOS=YL/RANGE
      ZLCOS=ZL/RANGE
C
C    COMPUTE DIRECTION COSINES OF VECTOR TO WEAPON OR POINT
C
      R=SQRT(XS**2.+YS**2.+ZS**2.)
      XSCOS=XS/R
      YSCOS=YS/R
      ZSCOS=ZS/R
C
C
C    COMPUTE ANGLES [illegible]
C
      [illegible]
      [illegible]
      [illegible]
```

```
      C
      C   IF COM IS LESS THAN PI/2., EARTH INTERFERENCE IS IMPOSSIBLE FOR ANY MODE.
      C
            PI=ACOS(-1.)
            IF(COM.LT.(PI/2.))S=1.
            IF(COM.LT.(PI/2.))GO TO 250
            PSI=ABS(PI/2.-COM)
      C
      C   IF COM IS GREATER THAN PI/2. + OR - 10 DEGREES, AND THE WEAPON IS
      C   GROUND-BASED, A SHOT IS PROHIBITED.
      C
            MODENO=WEAPON(3,WEAPNO)
      C
      C   CHECK EARTH INTERFERENCE WITH SHOT.
      C   (MODES 2 AND 3 ONLY).
            IF(MODENO.EQ.1)GO TO 250
      C
            S=1.
            PROJ1=RRCOS(PSI)
            REARTH=5920.
            IF(PROJ1.LT.REARTH)S=0.
            IF(S.EQ.0.)GO TO 300
      C
      C
      C   CHECK MAX FIRE RANGE
      C
  250       RANMAX=WEAPON(4,WEAPNO)
            IF(RANMAX.LT.RANGE)S=0.
            IF(S.EQ.0.)GO TO 300
            IF((COM.GT.(PI/2.-.1745)).AND.(MODENO).EQ.1.))S=0.
            IF((COM.GT.(PI/2.-.1745)).AND.(MODENO).EQ.1.))GO TO 300
            CALL PROP( [illegible] ,WEAPNO,CONCON,RANGE,TCT)
            CALL IFRSCT(TCT, [illegible] (1,WEAPNO),T,TITNO,XIRTME)
            IF(ITINO.GT.1)GO TO 290
  290       CONTINUE
      C
      C
      C   CHECK MAX IRRADIATION TIME ALLOWED AGAINST THAT REQUIRED
      C   FOR TARGET NEGATION
      C
            IF(XIRTME.GT.WEAPON(5,WEAPNO))S=0.
            IF(S.EQ.0.)GO TO 300
            S=1./XIRTME
  300       CONTINUE
      C
      C   APPLY PRIORITY WEIGHTING.
      C
      C   ITAR IS THE CODE TARGET TYPE ASSOCIATED WITH TARGET ITINO.
      C
            ITAR=IT(1,ITNO)
      C
      C
            [illegible]
            RETURN
            END
```

```
      SUBROUTINE PROP(WEAPON,WEAPNO,COS,RANGE,IOT)
      REAL IO,IOT,LAM,NSIG
      INTEGER WEAPNO
      DIMENSION WEAPON(11,5)
C
C*****  VARIABLE DEFINITIONS ARE AS FOLLOWS*****
C
C   F= 1. FOR GROUND, 2. FOR AIR, AND 3. FOR SPACE BASING
C   IO= INITIAL BEAM INTENSITY
C   WO= INITIAL BEAM WAIST SIZE, (0. IF BEAM IS FOCUSED)
C   LAM= WAVELENGTH
C   NSIG= N*SIGMA
C   COS= COS(THETA)  FOR AIR AND GROUND WEAPONS
C   ALT= AIRCRAFT ALTITUDE
C   RANGE= DISTANCE FROM WEAPON TO TARGET.
C
C
C
C   CONVERT RANGE IN KM TO METERS.
C
      RANGE=RANGE*1000.
C
C   CALCULATE BEAM WAIST SIZE AT TARGET.
C
      WO=WEAPON(3,WEAPNO)
      LAM=WEAPON(1,WEAPNO)
C
C   CONVERT LAM IN NANOMETERS TO METERS.
C
      LAM=LAM/1000000000.
      F=WEAPON(5,WEAPNO)
      IO=WEAPON(2,WEAPNO)
      X=1.
      NSIG=X*WEAPON(11,WEAPNO)
      ALT=WEAPON(10,WEAPNO)
C
C   CONVERT ALT IN KM TO METERS.
C
      ALT=ALT*1000.
      PI=ACOS(-1.)
      WT=WO*SQRT(1.+(LAM*RANGE/(PI*(WO**2.)))**2.)
C
C   CHECK WHETHER GROUND, AIR OR SPACE BASED WEAPON
C
 10   IF(F.EQ.1.)GO TO 20
      IF(F.EQ.2.)GO TO 30
C
C   CALCULATE IOT FOR SPACE WEAPON  [illegible]
C
      IOT=IO*((WO/WT)**2.)
      GO TO 100
C
C   CALCULATE IOT FOR GROUND WEAPON  [illegible]
C
 20   CONTINUE
      IOT=IO*((WO/WT)**2.)*EXP(-(NSIG*(-[illegible]
      GO TO [illegible]
```

```
C
C     CALCULATE IOT FOR AIR WEAPON
C
 30      CONTINUE
C
C     POWER= EXPONENTIAL TERM
C
         POWER=((-0.5)*[illegible]EXP(-ALT/8.5))/COS
         IOT=IO*EXP(POWER)*(R0/RT)**2.
 100     CONTINUE
         RETURN
         END
```

```
      SUBROUTINE [illegible](IOT,LAM,T,ISTMD,XIRTME)
      INTEGER ISTMD,ITYPE
      REAL IOT,LAM
      DIMENSION T(14,10)
C
      XTYPE=T(ISTMD,1)
      IF((XTYPE.GE.1.).AND.(XTYPE.LE.6.))ITYPE=1
      IF((XTYPE.GE.7.).AND.(XTYPE.LE.8.))ITYPE=2
      IF((XTYPE.GE.9.).AND.(XTYPE.LE.11.))ITYPE=3
      IF((XTYPE.GE.12.).AND.(XTYPE.LE.14.))ITYPE=4
C   FAILURE CURVES CALCULATED IN JOULES/CM**2.
C   CONVERT IOT FROM JOULES/M**2. TO JOULES/CM**2.
C
      IOT=IOT/10000.
      XIRTME=0.
      SQUIRT=SQRT(30.0./LAM)
      RIGHT=IOT*SQUIRT
      IF(((ITYPE.EQ.1).OR.(ITYPE.EQ.4)).AND.
     C(RIGHT.GT.33.))XIRTME=.0001
      IF(((ITYPE.EQ.1).OR.(ITYPE.EQ.4)).AND.
     C(RIGHT.LT.13.2))XIRTME=999999.
      IF((ITYPE.EQ.2).AND.(RIGHT.GT.420.))XIRTME=.0001
      IF((ITYPE.EQ.2).AND.(RIGHT.LT.52.))XIRTME=999999.
      IF((ITYPE.EQ.3).AND.(RIGHT.GT.77.))XIRTME=.0001
      IF((ITYPE.EQ.3).AND.(RIGHT.LT.4.2))XIRTME=999999.
C
C   IF THE "RIGHT" VALUE IS WITHIN LIMITS, CALCULATE XIRTME.
C
      IF(XIRTME.NE.0.)GO TO 100
      RIGHT=4.*T(ITYPE,7)*RIGHT
      PAREN=T(ITYPE,9)**2.-(4.*T(ITYPE,7)*T(ITYPE,8))+RIGHT
      XIRTME=(-T(ITYPE,9)-SQRT(PAREN))/(2.*T(ITYPE,7))
  100 CONTINUE
C
C   XIRTME IS THE IRRADIATION TIME REQUIRED TO NEGATE THE TARGET.
C
      RETURN
      END
```

```
      SUBROUTINE BATTLE(TACTICS,MISSION,HELSEL,T,WEAPON,TARORD,XT,YT,ZT,
     CJD)
      REAL IO,IOT,LAM,NSIG
      DIMENSION HELSEL(50,6),T(14,13),TARORD(14),MATTER(50,14),
     C WEAPON(11,5),XW(50),YW(50),ZW(50),TIME(50,4),XT(14),
     C YT(14),ZT(14),ATTER(50,14),MISSION(4,4),TACTICS(4,3)
      COMMON E,XM
      EXTERNAL F
C
C     THE PURPOSE OF BATTLE IS TO ALLOW THE WEAPONS TO FIRE AGAINST THE TARGETS
C     OVER THE MISSION NEGATION TIME, IN ACCORDANCE WITH THE MISSION REQUIREMENTS
C     AND TACTICS SPECIFIED BY THE USER.
C
C
C     A 50 BY 4 MATRIX (TIME) IS USED TO STORE THE FOLLOWING VARIABLES...
C
C        WEAPON SELECTION NUMBER.
C        OPERATING CYCLES USED FOR THIS WEAPON.
C        TAVAIL (TIME UNTIL WEAPON WILL BE AVAILABLE AGAIN).
C        XM  (MEAN ANOMALY OR PHI ANGLE).
C
C     THE WEAPON SELECTIONS ARE TAKEN FROM THE HELSEL MATRIX GENERATED BY
C     OPTIMIZE.
C
C     ZERO THE TIME MATRIX.
C
      PI=ACOS(-1.)
      DO 10 I=1,50
      DO 5 J=1,4
      TIME(I,J)=0.
    5 CONTINUE
   10 CONTINUE
C
C     COUNT HOW MANY WEAPONS ARE IN HELSEL (JW).
C
      JW=0
      DO 20 I=1,50
      IF(HELSEL(I,1).NE.0.)JW=JW+1
   20 CONTINUE
C
C     THE TARGETS AVAILABLE ARE REGISTERED IN MATRIX TARORD (TARGET ORDER [illegible])
C     TARORD MATRIX IS THE FIRST COLUMN OF THE T MATRIX.
C
C     GENERATE THE TARORD MATRIX.
C
      DO 30 I=1,14
      TARORD(I)=T(I,1)
   30 CONTINUE
C
C     START CLOCK AT 0 MINUTES.
C
      TE=-5.
C
   60 TE=TE+5.
C
C     IF TE=0., CALL SUBROUTINE TARGET TO INITIALLY PLACE THE TARGETS.
C
```

```
      IF(T[illegible].[illegible].)CALL TAR[illegible]T(T,XT,YT,ZT)
C
C     PRINT INITIAL TARGET LOCATIONS FOR THIS BATTLE.
C
      IF(T[illegible].NE.[illegible].)GO TO 42
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*," "
      PRINT*,"** INITIAL TARGET LOCATIONS FOR THIS BATTLE **"
      PRINT*," "
      PRINT*," "
      DO 41 I=1,14
      IF(TAROPP(I).EQ.[illegible].)GO TO 41
      PRINT*,"TARGET ",I,".  XT= ",XT(I),"  YT= ",YT(I),"  ZT= ",ZT(I)
41    CONTINUE
      PRINT*," "
      PRINT*," "
      PRINT*," "
42    CONTINUE
C
C     IF TS=0., SKIP THE NEXT SECTION.
C
      IF(T[illegible].EQ.[illegible].)GO TO 49
C
C*****************************************************************************
C
C     MOVE THE TARGETS ALONG THEIR ORBITS TO CORRESPOND TO THE 5 MINUTE TIME
C     INCREMENT.
C
      DO 48 I=1,14
C
C     CHECK WHETHER THE TARGET IS AVAILABLE.
C
      IF(TAROPP(I).EQ.[illegible].)GO TO 48
C
C     ADVANCE THE MEAN ANOMALY.
C
      XMU=398601.2
      CU[illegible]A=(T(I,2))**3.
C
C     DELXM IS THE MEAN ANOMALY INCREMENT.
C
      DELXM=SQRT(XMU/CU[illegible]A)*[illegible].
C
C
C     UPDATE THE MEAN ANOMALY IN MATRIX T.
C
47    T(I,[illegible])=T(I,[illegible])+DELXM
      [illegible]=T(I,3)
      IF([illegible].EQ.[illegible].)[illegible]TA=T(I,[illegible])
      IF([illegible].[illegible].[illegible].)GO TO 4[illegible]
      [illegible]=T(I,[illegible])
      A=X[illegible]-2.[illegible]
      [illegible]=[illegible]+2.[illegible]
      CALL [illegible]([illegible],[illegible],[illegible],[illegible],IER)
      EAN=[illegible]
```

```
      [illegible]COS([illegible])/([illegible](ZAM,-1.))
   46 CONTINUE
      R=T(I,2)*(1.-T(I,3)**2.)/(1.+T(I,3)*COS(ETA))
      THETA=(PI/2.)-(T(I,4)*SIN(T(I,5)+ETA))
      PHIS=T(I,5)+(T(I,6)+ETA)*COS(T(I,4))
      XT(I)=R*SIN(THETA)*COS(PHIS)
      YT(I)=R*SIN(THETA)*SIN(PHIS)
      ZT(I)=R*COS(THETA)
   48 CONTINUE
C
C   PRINT TARGET LOCATIONS AT CURRENT CLOCK TIME.
C
      PRINT*,"TARGET LOCATIONS AT T3= ",T3
      PRINT*," "
      PRINT*," "
      DO 45 I=1,14
      IF(TARDPP(I).EQ.1.)GO TO 45
      PRINT*,"TARGET ",I,".  XT= ",XT(I),"  YT= ",YT(I),"  ZT= ",ZT(I)
   45 CONTINUE
      PRINT*," "
      PRINT*," "
      PRINT*," "
   49 CONTINUE
C
C   TARGET COORDINATE MATRICES XT, YT, AND ZT ARE NOW UPDATED WITH CURRENT
C   TARGET POSITIONS.
C
C*****************************************************************************
C
C   NOW MOVE THE WEAPONS ALONG THEIR ORBITS OR LATITUDES.
C
      DO 55 I=1,JW
C
C   CHECK WHETHER WEAPON HAS EXCEEDED ITS OPERATING CYCLE LIMIT.
C
      WEAPNO=[illegible](I,1)
      [illegible]=WEAPNO
      IF(TIME(I,2).[illegible].WEAPON(4,[illegible]))GO TO 5[illegible]
C
C   DO GROUND- AND AIR-BASED WEAPONS FIRST.
C
C   [illegible]
C
C   THE FOLLOWING [illegible] GIVES THE INITIAL PLACEMENT OF THE GROUND-
C   AND AIR-BASED WEAPONS.
C
      IF(T[illegible].NE.0.)GO TO 5[illegible]
      [illegible]=RANF(DUM)
      TIME(I,[illegible])=[illegible]
      IF([illegible].EQ.3.)GO TO 5[illegible]
C
C   UPDATE THE [illegible].
C
C   [illegible]
C   [illegible]
C
      GO TO 5[illegible]
```

```
53    CONTINUE
      IF(WEAPON(9,INFP).EQ.0.)GO TO 52
      TIME(I,4)=TIME(I,4)+.0013155156
51    CONTINUE
      R=WEAPON(1,INFP)+6371.145
      THETA=HELSEL(I,2)
      PHIS=TIME(I,4)
C
C     CALCULATE CARTESIAN COORDINATES FOR THE WEAPON LOCATION AT THE CURRENT
C     TIME.
C
      GO TO 54
52    CONTINUE
C
C**************************************************************************
C
C     FOLLOWING SECTION MOVES THE SPACE- ASED WEAPONS ALONG THEIR ORBITS.
C
C     ADVANCE THE MEAN ANOMALY.
C
      IF(T1.EQ.0.)GO TO 56
      CUBEA=(HELSEL(I,2))**3.
      DELKM=SQRT(XMU/CUBEA)*30.
C
C     UPDATE THE MEAN ANOMALY.
C
      TIME(I,4)=TIME(I,4)+DELKM
C
C     CALCULATE THE SPHERICAL COORDINATES.
C
56    CONTINUE
      IF(T1.NE.0.)GO TO 57
      RN=RANF(DUM)
      TIME(I,4)=RN*PI*2.
57    CONTINUE
      ETA=TIME(I,4)
      R=HELSEL(I,2)
      THETA=PI/2.-ETA
      PHIS=HELSEL(I,4)+ETA
C
C     CALCULATE THE CARTESIAN COORDINATES.
C
54    XW(I)=R*SIN(THETA)*COS(PHIS)
      YW(I)=R*SIN(THETA)*SIN(PHIS)
      ZW(I)=R*COS(THETA)
55    CONTINUE
C
C     PRINT LOCATIONS OF WEAPONS.
C
      IF(T1.EQ.0.)PRINT*,"** INITIAL WEAPON LOCATIONS **"
      IF(T1.NE.0.)PRINT*,"** WEAPON LOCATIONS AT T = ",T1
      PRINT*," "
      PRINT*," "
      [illegible]
      PRINT*,"[illegible]",I15,"[illegible]",[illegible]," [illegible] ",[illegible]
     1),"  ZW= ",ZW(I99)
50    CONTINUE
```

```
C
C     SO ALL THE USABLE WEAPONS ARE MOVED ALONG THEIR RESPECTIVE PATHS.
C
C*****************************************************************************
C
C     ZERO THE LATTICE MATRIX.
C
      DO 60 I=1,JN
      DO 65 J=1,15
      LATTIC(I,J)=0.
65    CONTINUE
60    CONTINUE
C
C     ADJUST THE TIME MATRIX ELEMENT TAVAIL.
C
      DO 70 I=1,JN
      TIME(I,2)=TIME(I,3)-5.
      IF(TIME(I,2).LT.0.)TIME(I,2)=0.
70    CONTINUE
C
C*****************************************************************************
C
C     CALL SIGHT TO BUILD LATTICE FOR ALL SURVIVING TARGETS OVER ALL
C     CURRENTLY USABLE WEAPONS.
C     NOTE..."USEABLE" MEANS THE WEAPON HAS NOT EXCEEDED ITS OPERATING CYCLE LIMIT
C     AND "CURRENTLY USEABLE" MEANS THE WEAPON ALSO IS NOT STAING OR BEING
C     RECYCLED.
C
      DO 100 I=1,JN
C
C     IF THE ITH WEAPON IS NOT CURRENTLY USEABLE, GO TO THE NEXT WEAPON.
C
C
      WEAPTY=IELSIL(I,1)
      NWEAP=WEAPTY
C
C     [illegible]
C
      IF((TIME(I,2).GT.WEAPON(4,NWEAP)).OR.(TIME(I,3).GT.0.))GO TO 100
C
      DO 90 J=1,IN
C
C     IF THE JTH TARGET HAS BEEN NEUTRALIZED, GO TO THE NEXT TARGET.
C
      IF(TARGET(J).EQ.0.)GO TO 90
C
C     CALL SIGHT FOR THE JTH TARGET AND THE ITH WEAPON.
C
      [illegible]
      CALL SIGHT(LATTIC,I,[illegible],[illegible],T,XP(I),YP(I),ZP(I),
     [illegible]
C
C     [illegible]
C     [illegible]
C
C
C     [illegible]
```

```
C
      ITAR=T(J,1)
      S=C/MISSION(ITAR,4)
      BATTER(I,J)=1./S
 90   CONTINUE
      PRINT*,"STATEMENT 90 REACHED."
 100  CONTINUE
C
C   BATTER NOW CONTAINS ZEROS WHERE A WEAPON TO TARGET FIRING POSSIBILITY IS
C   IMPOSSIBLE DUE TO ANY OF THE FOLLOWING REASONS...
C
C      WEAPON HAS EXCEEDED ITS OPERATING CYCLE LIMIT.
C      WEAPON IS CURRENTLY FIRING OR RECYCLING.
C      TARGET HAS ALREADY BEEN NEGATED.
C      LINE OF SIGHT, IRRADIATION TIME, OR RANGE IS EXCEEDED.
C
C   BATTER ALSO CONTAINS INVERSE IRRADIATION TIMES IN ALL OTHER LOCATIONS.
C
C
C*****************************************************************************
C
C   FIRE THE WEAPONS AGAINST THE TARGETS.
C
C   IF FIRING PRIORITIES WERE NOT ASSIGNED, I9=4
C   IF FIRING PRIORITIES WERE ASSIGNED, I9 = 1
C
      I9=1
      IF((TACTIC(1,2).EQ.4.).AND.
     C(TACTIC(2,2).EQ.4.).AND.
     C(TACTIC(3,2).EQ.4.).AND.
     C(TACTIC(4,2).EQ.4.)) I9=4
C
      DO 300 IPRIOR=1,4
      PRIPIR=IPRIOR
C   BATTER2 MATRIX (50 BY 14) IS USED TO RECORD THE BATTER VALUES FOR
C   PRIORITY PRIPIR TARGETS.
C
C   ZERO THE BATTER2 MATRIX.
C
      DO 150 I=1,50
      DO 140 J=1,14
      BATTER2(I,J)=0.
 140  CONTINUE
 150  CONTINUE
      PRINT*,"STATEMENT 150 REACHED."
C
C
      DO 200 I=1,14
      DO 190 J=1,14
C
C   I IS THE WEAPON SELECT NUMBER, AND J IS THE TARGET NUMBER.
C
C   IF THE JTH TARGET IS NOT OF PRIORITY PRIPIR, GO TO THE NEXT TARGET.
C
      X1=T(J,1)
      M1=X1
C
```

```
      IF(TACTIC([illegible]).[illegible].PRIFIT)[illegible] TO 19[illegible]
C
      SATEF2(I,J)=SATTEF(I,J)
19[illegible]   CONTINUE
200   CONTINUE
C
C     COUNT THE NUMBER OF TARGETS CURRENTLY LEFT (K2).
C
      K2=0
      DO 180 I=1,14
      IF(TARGPP(I).NE.0.)K2=K2+1
180   CONTINUE
      PRINT*,"STATEMENT 180 REACHED"
C
      JWW=JW*K2
      DO 290 III=1,JWW
C
C     SO SATEF2 CONTAINS ONLY THE INVERSE IRRADIATION TIMES FOR THE PRIFIP
C     PRIORITY TARGETS.
C
C     IF NO RANKING BY IRRADIATION TIME WAS SELECTED, SKIP THE NEXT SECTION.
C
      C42=0.
      IF((TACTIC(1,3).NE.1.).AND.(TACTIC(2,3).NE.1.).AND.
     C(TACTIC(3,3).NE.1.).AND.(TACTIC(4,3).NE.1.))C42=1.
      IF((T3.EQ.0.).AND.(I3.EQ.4).AND.(C42.EQ.1.))PRINT*,"FIRING WITHO
     CUT PRIORITIES AND WITHOUT SORTING BY IRRADIATION TIMES."
      IF((T3.EQ.[illegible]).AND.(I3.EQ.4).AND.(C42.EQ.0.))PRINT*,"FIRING WITH
     COUT PRIORITIES BUT SORTING BY IRRADIATION TIMES."
      IF((T3.EQ.0.).AND.(I3.EQ.1).AND.(C42.EQ.1.))PRINT*,"FIRING WITH
     C PRIORITIES, BUT WITHOUT SORTING BY IRRADIATION TIMES."
      IF((T3.EQ.0.).AND.(I3.EQ.1).AND.(C42.EQ.0.))PRINT*,"FIRING WITH
     C PRIORITIES AND WITH SORTING BY IRRADIATION TIMES."
      IF((TACTIC(1,3).NE.1.).AND.(TACTIC(2,3).NE.1.).AND.
     C(TACTIC(3,3).NE.1.).AND.(TACTIC(4,3).NE.1.))GO TO 250
C
C     FIRE AT THE TARGET WITH THE LEAST IRRADIATION TIME.
C
      AMAX=0.
      DO 240 I2=1,JW
      DO 230 J2=1,K2
      IF(SATEF2(I2,J2).GT.AMAX)MAXI=I2
      IF(SATEF2(I2,J2).GT.AMAX)MAXJ=J2
      IF(SATEF2(I2,J2).GT.AMAX)AMAX=SATEF2(MAXI,MAXJ)
230   CONTINUE
240   CONTINUE
C
      IF(AMAX.EQ.0.)GO TO [illegible]
C
C     FIRE THE MAXI WEAPON AGAINST THE MAXJ TARGET.
C
C     UPDATE THE TIME MATRIX AND THE TARGPP MATRIX TO REFLECT WEAPON USE AND
C     TIME OF [illegible].
C
      [illegible]
[illegible]   CONTINUE
      K1=0
```

```
C
C   SELECT A TARGET RANDOMLY...
C        ...FROM THE ENTIRE MATRIX IF NO FIRING PRIORITIES.
C        ...FROM THE BATTER2 MATRIX IF FIRING PRIORITIES WERE ASSIGNED.
C
      RN=RANF(DUM)
      RN=RN*5.
      IRN=RN
      RN=RANF(DUM)
      RN=RN*15.
      JRN=RN
C
C   IF NO FIRING PRIORITIES, GO TO 248.
C
      IF(IO.EQ.4)GO TO 248
      IF(BATTER2(IRN,JRN).EQ.0.)K1=K1+1
      GO TO 249
248   IF(BATTER(IRN,JRN).EQ.0.)K1=K1+1
249   CONTINUE
      IF(K1.GT.1000)PRINT*,"*****K1 GREATER THAN 1000*****"
      IF(K1.GT.1000)GO TO 300
C
C   IF PRIORITIES WERE ASSIGNED, GO TO 251
C
      IF(IO.EQ.1)GO TO 251
      IF(BATTER(IRN,JRN).EQ.0.)GO TO 250
C
C   IF PRIORITIES WERE NOT ASSIGNED, GO TO 252.
C
      IF(IO.EQ.4)GO TO 252
251   IF(BATTER2(IRN,JRN).EQ.0.)GO TO 250
252   CONTINUE
      MAXI=IRN
      MAXJ=JRN
C
C   INCREMENT [illegible] CYCLES USED BY [illegible].
C
245   TIME(MAXI,2)=TIME(MAXI,2)+1.
      INEAP=[illegible](MAXI,1)
C
C
C   IF TARGET PRIORITIES WERE NOT ASSIGNED, GO TO 247
C
      IF(IO.EQ.4)GO TO 247
C
C   UPDATE THE WEAPON AVAILABILITY TIME TAVAIL.
C
      TIME(MAXI,3)=[illegible](MAXI,MAXJ)+[illegible](5,INEAP)
C
C   ZERO THE [illegible] VALUE.
C
      BATTER2(MAXI,MAXJ)=0.
C
C   [illegible]
C
      IF([illegible]) GO TO [illegible]
247   [illegible](MAXI,MAXJ)+[illegible](5,INEAP)
```

```
240   BATTER(IMAT,MAXJ)=1.
C
C     CANCEL THE TARGET FROM THE TAROPP MATRIX.
C
      TAROPP(MAXJ)=0.
C
C     PRINT TARGET NUMBER JUST NEGATED.
C
      PRINT*,"TARGET NUMBER ",MAXJ," NEGATED."
      PRINT*," "
      PRINT*," "
C     CHECK WHETHER THE TARGET TYPE NEGATION PERCENTAGE HAS BEEN MET.
C
      TYPE=T(MAXJ,1)
      ITYPE=TYPE
      IF(ITYPE.EQ.1)NUMTAR=5
      IF(ITYPE.EQ.2)NUMTAR=2
      IF(ITYPE.EQ.3)NUMTAR=3
      IF(ITYPE.EQ.4)NUMTAR=3
      XNUMTR=NUMTAR
C
C     COUNT THE NUMBER OF TARGETS OF ITYPE WHICH HAVE BEEN NEGATED.
C
      IF(ITYPE.EQ.1)GO TO 225
      IF(ITYPE.EQ.2)GO TO 224
      IF(ITYPE.EQ.3)GO TO 223
      X3=0.
      DO 222 J4=12,14
      IF(TAROPP(J4).EQ.0.)X3=X3+1.
222   CONTINUE
      PERCNT=X3/XNUMTR
      IF(PERCNT.LT.MISSION(ITYPE,2))GO TO 226
      DO 221 J4=12,14
      TAROPP(J4)=0.
221   CONTINUE
      GO TO 226
C
C
223   CONTINUE
      X3=0.
      DO 220 J3=9,11
      IF(TAROPP(J3).EQ.0.)X3=X3+1.
220   CONTINUE
      PERCNT=X3/XNUMTR
      IF(PERCNT.LT.MISSION(ITYPE,2))GO TO 226
      DO 219 J3=9,11
      TAROPP(J3)=0.
219   CONTINUE
      GO TO 226
C
C
224   CONTINUE
      X3=0.
      [illegible]
      [illegible]
[illegible]   [illegible]
      [illegible]
```

```
      IF(PERCNT.LT.MISSION(TTYPE,2)) GO TO 226
      DO 217 J4=7,9
      TARGPP(J4)=0.
217   CONTINUE
C
C
225   CONTINUE
      X3=0.
      DO 215 J4=1,6
      IF(TARGPP(J4).EQ.0.)X3=X3+1.
215   CONTINUE
      PERCNT=X3/XNUMTR
      IF(PERCNT.LT.MISSION(TTYPE,2))GO TO 226
      DO 215 J4=1,6
      TARGPP(J4)=0.
215   CONTINUE
C
C
226   CONTINUE
C
C   IF ALL OF THE TARGETS ARE NEGATED, STOP THE BATTLE BEFORE TIME.
C
      J9=0
      DO 210 J4=1,14
      IF(TARGPP(J4).EQ.0.)J9=J9+1
210   CONTINUE
      IF(J9.EQ.14) PRINT*,"BATTLE WAS STOPPED AT ",TS," DUE TO MISSION
     C ACCOMPLISHMENT"
      IF(J9.EQ.14) GO TO 1000
200   CONTINUE
300   CONTINUE
C
C   IF BATTLE HAS NOT BEEN RUN FOR THE MISSION [illegible] TIME, GO TO 40.
C
      DO 400 I=1,14
      IF(T(I,1).NE.0.) T(I,1)=JJJ
      IF(T(I,1).NE.0.)GO TO [illegible]
400   CONTINUE
500   CONTINUE
      IF(TS.LT.MISSION(JJJ,3))GO TO 40
C
C
C*****************************************************************************
1000  CONTINUE
      RETURN
      END
```

```
      PROGRAM CSG(INPUT,OUTPUT)
      DIMENSION X(1,1650), Y(1,1650),Z(1,1650),PHI(1650),
     C TH(37), ORBITS(825,36)
      REAL LOWER, MIDDLE,UPPER
      INTEGER SO, ORBITS, POINT
C
C   THE PURPOSE OF THIS PROGRAM IS TO DEVELOP THE ORBITS(IORBIT,JPOINT)
C     MATRIX TO BE USED BY OPTIMIZE.
C
C   A VALUE IN THIS MATRIX IS THE POINT NUMBER WHICH IS THE POINT ON THE
C     SPHERE OF OPERATIONS NEAREST THE ORBITAL POINT BEING CONSIDERED.
C
C   A "NEAREST POINT" IS NEEDED FOR EACH OF THE 36 POINTS ON EACH OF
C   THE 825 POSSIBLE ORBITS.
C
      IO=0
      CALL SPHERE (1.,1,X,Y,Z,TH,PHI)
      M=1
      N=36
      GO TO 5
1     M=73
      N=861
5     DO 100 I=M,N
      DO 90 J=1,36
C
C   HALF OF THE 1650 POINTS ON A SPHERE OF OPERATIONS ARE USED AS UNIT
C     MOMENTUM VECTORS TO DEFINE 825 DISTINCT ORBITAL POSSIBILITIES.
C     I IS THE POINT NUMBER ON THE SPHERE OF OPERATIONS, AND
C     J IS THE JTH POINT ON THE ITH ORBIT.
C
C   FOR EACH UNIT VECTOR, THE FIRST POINT IN THE ORBIT MUST BE FOUND.
C
      IF(J.NE.1) GO TO 20
C
C   ROTATE THE REFERENCE SYSTEM THROUGH THE ANGLE PHI(I) ABOUT THE Z0 AXIS,
C     AND THEN THROUGH THE ANGLE ANG1 ABOUT THE Y0 AXIS.
C
C   A "FORWARD" ROTATION MATRIX IS USED TO DO THIS.
C   X(1,I), Y(1,I), Z(1,I), PHI(I), AND TH ARE THE CARTESIAN AND SPHERICAL
C     COORDINATES OF THE SPHERE OF OPERATIONS POINT (I).
C
C   ANG1 = THETA 0,M  -  PI/2.
C
      IF((I.GE.0).AND.(I.LE.72))THETOM=TH(1)
      IF((I.GE.73).AND.(I.LE.144))THETOM=TH(2)
      IF((I.GE.145).AND.(I.LE.215))THETOM=TH(3)
      IF((I.GE.216).AND.(I.LE.285))THETOM=TH(4)
      IF((I.GE.286).AND.(I.LE.353))THETOM=TH(5)
      IF((I.GE.354).AND.(I.LE.418))THETOM=TH(6)
      IF((I.GE.419).AND.(I.LE.480))THETOM=TH(7)
      IF((I.GE.481).AND.(I.LE.539))THETOM=TH(8)
      IF((I.GE.540).AND.(I.LE.594))THETOM=TH(9)
      IF((I.GE.595).AND.(I.LE.64[illegible]))THETOM=TH(10)
      IF((I.GE.6[illegible]).AND.(I.LE.69[illegible]))THETOM=TH(11)
      IF((I.GE.693).AND.(I.LE.732))THETOM=TH(12)
      IF((I.GE.733).AND.(I.LE.768))THETOM=TH(13)
      IF((I.GE.769).AND.(I.LE.7[illegible]))THETOM=TH(14)
```

```
      IF((I.GE.799).AND.(I.LE.823))THETOM=TH(15)
      IF((I.GE.824).AND.(I.LE.842))THETOM=TH(16)
      IF((I.GE.843).AND.(I.LE.855))THETOM=TH(17)
      IF((I.GE.856).AND.(I.LE.860))THETOM=TH(18)
      IF(I.EQ.851)THETOM=TH(19)
      PI=ACOS(-1.)
      PHIOM=PHI(I)
      ANG1=THETOM-PI/2.
C
C---XRM, YRM AND ZRM ARE THE COORDINATES OF THE "UNIT MOMENTUM VECTOR"
C     GOING THROUGH POINT I IN THE ROTATED REFERENCE SYSTEM.
C
C   XOM, YOM, AND ZOM ARE THE COORDINATES OF THE SAME "UNIT MOMENTUM VECTOR"
C     IN THE ORIGINAL REFERENCE SYSTEM.
C
      XOM=X(1,I)
      YOM=Y(1,I)
      ZOM=Z(1,I)
C
C---FORWARD ROTATION MATRIX ELEMENTS
C
C---NOTE... ALL ELEMENTS ARE NOT NEEDED, SINCE YRM AND ZRM WILL =0.
C
      ANG11=COS(ANG1)*COS(PHIOM)
      ANG12=COS(ANG1)*SIN(PHIOM)
      ANG13=-SIN(ANG1)
C
      XRM=ANG11*XOM+ANG12*YOM+ANG13*ZOM
      YRM=0.
      ZRM=0.
C
C---COMPUTE THE ROTATED COORDINATES OF THE JTH ORBITAL POINT.  IN GENERAL,
C     THE ROTATED COORDINATES OF THE JTH POINT IN THE ORBIT ARE XRJ, YRJ,
C     AND ZRJ.  THE ORIGINAL REFERENCE SYSTEM COORDINATES OF THE JTH POINT ARE
C     XOJ, YOJ, AND ZOJ.
C
C   THE (XRJ, YRJ AND ZRJ) ROTATED COORDINATES MUST BE ROTATED BACKWARD TO
C     TO THE ORIGINAL REFERENCE SYSTEM.
C
      BANG=PI/2.-THETOM
      BANG11=COS(PHIOM)*COS(BANG)
      BANG12=-SIN(PHIOM)
      BANG13=-COS(PHIOM)*SIN(BANG)
      BANG21=SIN(PHIOM)*COS(BANG)
      BANG22=COS(PHIOM)
      BANG23=-SIN(PHIOM)*SIN(BANG)
      BANG31=SIN(BANG)
      BANG32=0.
      BANG33=COS(BANG)
C
C    COORDINATES OF THE FIRST POINT
C
      RHO=1.
      IF(J.NE.1)GO TO 10
      XRJ=0.
      YRJ=0.
      ZRJ=XRM
```

```
      C
      C   SPHERICAL COORDINATES OF THE JTH POINT IN THE ROTATED REFERENCE SYSTEM.
      C
      10    IF(J.EQ.1)GO TO 30
      C
      C   RHO= R OF THE SPHERE OF OPERATIONS
      C   THETA IS ROTATED A POSITIVE 10 DEGREES WITH EACH SUCCEEDING POINT OF THE
      C     ORBIT.
      C   PHIRJ IS PI/2. AND IS CONSTANT FOR ALL POINTS OF A GIVEN ORBIT.
      C
      20    CONTINUE
            PHIRJ=PI/2.
            XJ=J
            THETRJ=10.*XJ*PI/180.
      C
      C   CARTESIAN COORDINATES OF THE JTH POINT IN THE ROTATED REFERENCE SYSTEM.
      C
            XRJ=0.
            YRJ=RHO*SIN(PHIRJ)
            ZRJ=RHO*COS(THETRJ)
      C
      30    CONTINUE
      C
      C   FOLLOWING ROTATES (XRJ, YRJ, ZRJ) BACKWARD TO THE ORIGINAL REFERENCE
      C     SYSTEM.
      C
            XOJ=RANG11*XRJ+RANG12*YRJ+RANG13*ZRJ
            YOJ=RANG21*XRJ+RANG22*YRJ+RANG23*ZRJ
            ZOJ=RANG31*XRJ+RANG32*YRJ+RANG33*ZRJ
      C
      C   FOLLOWING TRANSFORMS CARTESIAN COORDINATES TO SPHERICAL COORDINATES,
      C     BOTH IN THE ORIGINAL REFERENCE SYSTEM.
      C
            THETOJ=ACOS(ZOJ/RHO)
            IF(YOJ.LE.0.)GO TO 40
            PHIOJ=ACOS(XOJ/SQRT(XOJ**2.+YOJ**2.))
            IF(YOJ.GT.0.)GO TO 45
      40    PHIOJ=ASIN(YOJ/SQRT(XOJ**2.+YOJ**2.))
            IF(((XOJ.LE.0.).AND.(ZOJ.GT.0.)).OR.((XOJ.LE.0.).AND.
           S(ZOJ.LE.0.)))PHIOJ=-PHIOJ
      45    CONTINUE
      C
      C   WE NOW HAVE THE SPHERICAL COORDINATES OF THE JTH POINT OF THE ITH ORBIT.
      C
      C   THE FOUR POINTS ON THE SPHERE WHICH SURROUND THIS POINT MUST BE EXAMINED
      C     IN ORDER TO FIND THE CLOSEST ONE TO USE TO APPROXIMATE THE JTH POINT.
      C
      C   THE SPHERE OF OPERATIONS LATITUDES BOUND THE JTH POINT ON THE NORTH AND
      C     SOUTH.
      C
      C   UPDIFF IS THE NUMBER OF DEGREES BETWEEN THETOJ AND TH(II) WHEN
      C   TH(II) IS ABOVE THETOJ.
      C
      C   MUPDIF IS THE MINIMUM OF ALL UPDIFF'S.
      C
            MUPDIF=PI
            DO 50 II=1,37
```

```
      UPDIFF=THETAJ-TH(II)
      IF(UPDIFF.LT.0.)GO TO 50
      IF(UPDIFF.LT.MUPDIF)MUP=II
      IF(UPDIFF.LT.MUPDIF)MUPDIF=UPDIFF
   50 CONTINUE
C
C   SO TH(MUP) = THETA ABOVE THETAJ BY THE LEAST AMOUNT (MUPDIF).
C
C   LODIFF IS THE NUMBER OF DEGREES BETWEEN THETAJ AND TH(II)
C   BELOW THETAJ.
C   MLODIF IS THE MINIMUM OF ALL LODIFF S.
C
C
      MLODIF=PI
      DO 60 II=1,37
      LODIFF=TH(II)-THETAJ
      IF(LODIFF.LT.0.)GO TO 60
      IF(LODIFF.LT.MLODIF)MLO=II
      IF(LODIFF.LT.MLODIF)MLODIF=LODIFF
   60 CONTINUE
C
C   SO TH(MLO) = THETA BELOW THETAJ BY THE LEAST AMOUNT (MLODIF).
C
C   NOW WE NEED THE FLANKING PHI FOR THE EAST AND WEST SIDES OF THE
C     JTH POINT.
C
C   THE FOLLOWING STATEMENTS ESTABLISH PHI(ISTART) AND PHI(IEND)
C   POINTS FOR TH(MUP).
C
C
      IF(MUP.EQ.1)ISTART=1
      IF(MUP.EQ.1)IEND=72
      IF(MUP.EQ.2)ISTART=73
      IF(MUP.EQ.2)IEND=144
      IF(MUP.EQ.3)ISTART=145
      IF(MUP.EQ.3)IEND=215
      IF(MUP.EQ.4)ISTART=216
      IF(MUP.EQ.4)IEND=295
      IF(MUP.EQ.5)ISTART=296
      IF(MUP.EQ.5)IEND=353
      IF(MUP.EQ.6)ISTART=354
      IF(MUP.EQ.6)IEND=418
      IF(MUP.EQ.7)ISTART=419
      IF(MUP.EQ.7)IEND=480
      IF(MUP.EQ.8)ISTART=481
      IF(MUP.EQ.8)IEND=539
      IF(MUP.EQ.9)ISTART=540
      IF(MUP.EQ.9)IEND=594
      IF(MUP.EQ.10)ISTART=595
      IF(MUP.EQ.10)IEND=645
      IF(MUP.EQ.11)ISTART=646
      IF(MUP.EQ.11)IEND=691
      IF(MUP.EQ.12)ISTART=692
      IF(MUP.EQ.12)IEND=732
      IF(MUP.EQ.13)ISTART=733
      IF(MUP.EQ.13)IEND=7[illegible]
      IF(MUP.EQ.14)ISTART=76[illegible]
```

```
      IF(MUP.EQ.14)IEND=798
      IF(MUP.EQ.15)ISTART=799
      IF(MUP.EQ.15)IEND=823
      IF(MUP.EQ.16)ISTART=824
      IF(MUP.EQ.16)IEND=842
      IF(MUP.EQ.17)ISTART=843
      IF(MUP.EQ.17)IEND=854
      IF(MUP.EQ.18)ISTART=855
      IF(MUP.EQ.18)IEND=860
      IF(MUP.EQ.19)ISTART=1850
      IF(MUP.EQ.19)IEND=1850
      IF(MUP.EQ.20)ISTART=862
      IF(MUP.EQ.20)IEND=933
      IF(MUP.EQ.21)ISTART=934
      IF(MUP.EQ.21)IEND=1004
      IF(MUP.EQ.22)ISTART=1005
      IF(MUP.EQ.22)IEND=1074
      IF(MUP.EQ.23)ISTART=1075
      IF(MUP.EQ.23)IEND=1142
      IF(MUP.EQ.24)ISTART=1143
      IF(MUP.EQ.25)ISTART=1208
      IF(MUP.EQ.24)IEND=1207
      IF(MUP.EQ.25)IEND=1269
      IF(MUP.EQ.26)ISTART=1270
      IF(MUP.EQ.26)IEND=1328
      IF(MUP.EQ.27)ISTART=1329
      IF(MUP.EQ.27)IEND=1393
      IF(MUP.EQ.28)ISTART=1394
      IF(MUP.EQ.28)IEND=1434
      IF(MUP.EQ.29)ISTART=1435
      IF(MUP.EQ.29)IEND=1480
      IF(MUP.EQ.30)ISTART=1481
      IF(MUP.EQ.30)IEND=1521
      IF(MUP.EQ.31)ISTART=1522
      IF(MUP.EQ.31)IEND=1557
      IF(MUP.EQ.32)ISTART=1558
      IF(MUP.EQ.32)IEND=1577
      IF(MUP.EQ.33)ISTART=1578
      IF(MUP.EQ.33)IEND=1612
      IF(MUP.EQ.34)ISTART=1613
      IF(MUP.EQ.34)IEND=1631
      IF(MUP.EQ.35)ISTART=1632
      IF(MUP.EQ.35)IEND=1643
      IF(MUP.EQ.36)ISTART=1644
      IF(MUP.EQ.36)IEND=1649
      IF(MUP.EQ.37)ISTART=1650
      IF(MUP.EQ.37)IEND=1650
   61 CONTINUE
C
C     PHI(LEFT1) IS THE PHI OF THE POINT TO THE LEFT OF OUR MEDIAN ORIGINAL POINT.
C     PHI(RIGHT1) IS THE PHI OF THE POINT TO THE RIGHT OF OUR MEDIAN ORIGINAL POINT.
C
      [illegible]
      DO [illegible]
      [illegible]
      [illegible]
      [illegible]
```

```
      IF(DIFF.GE.0.)LPHI1=II-1
   65 CONTINUE
C
C     LPHI1 AND MPHI1 ARE BOUNDS ON PHI(J) FOR TH(MUP)
C
C
C     FOLLOWING STATEMENTS ESTABLISH PHI(ISTART) AND PHI(IEND) FOR TH(MLO).
C
C
      IF(MLO.EQ.1)ISTART=1
      IF(MLO.EQ.1)IEND=72
      IF(MLO.EQ.2)ISTART=73
      IF(MLO.EQ.2)IEND=144
      IF(MLO.EQ.3)ISTART=144
      IF(MLO.EQ.3)IEND=215
      IF(MLO.EQ.4)ISTART=216
      IF(MLO.EQ.4)IEND=285
      IF(MLO.EQ.5)ISTART=286
      IF(MLO.EQ.6)IEND=353
      IF(MLO.EQ.6)ISTART=354
      IF(MLO.EQ.6)IEND=418
      IF(MLO.EQ.7)ISTART=419
      IF(MLO.EQ.7)IEND=480
      IF(MLO.EQ.8)ISTART=481
      IF(MLO.EQ.8)IEND=539
      IF(MLO.EQ.9)ISTART=540
      IF(MLO.EQ.9)IEND=594
      IF(MLO.EQ.10)ISTART=595
      IF(MLO.EQ.10)IEND=645
      IF(MLO.EQ.11)ISTART=646
      IF(MLO.EQ.11)IEND=691
      IF(MLO.EQ.12)ISTART=692
      IF(MLO.EQ.12)IEND=732
      IF(MLO.EQ.13)ISTART=733
      IF(MLO.EQ.13)IEND=768
      IF(MLO.EQ.14)ISTART=769
      IF(MLO.EQ.14)IEND=799
      IF(MLO.EQ.15)ISTART=79[illegible]
      IF(MLO.EQ.15)IEND=823
      IF(MLO.EQ.16)ISTART=824
      IF(MLO.EQ.16)IEND=842
      IF(MLO.EQ.17)ISTART=843
      IF(MLO.EQ.17)IEND=854
      IF(MLO.EQ.18)ISTART=855
      IF(MLO.EQ.18)IEND=858
      IF(MLO.EQ.19)ISTART=[illegible]
      IF(MLO.EQ.19)IEND=[illegible]
      IF(MLO.EQ.20)ISTART=[illegible]
      IF(MLO.EQ.20)IEND=[illegible]
      IF(MLO.EQ.21)ISTART=[illegible]
      IF(MLO.EQ.21)IEND=[illegible]
      IF(MLO.EQ.22)ISTART=[illegible]
      IF(MLO.EQ.22)IEND=[illegible]
      IF(MLO.EQ.[illegible])ISTART=[illegible]
      IF(MLO.EQ.[illegible])IEND=[illegible]
      IF(MLO.EQ.[illegible])ISTART=[illegible]
      IF(MLO.EQ.24)IEND=[illegible]
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      IF(MLO.EQ.25)ISTART=1228
      IF(MLO.EQ.25)IEND=1269
      IF(MLO.EQ.26)ISTART=1270
      IF(MLO.EQ.26)IEND=1328
      IF(MLO.EQ.27)ISTART=1329
      IF(MLO.EQ.27)IEND=1373
      IF(MLO.EQ.28)ISTART=1374
      IF(MLO.EQ.28)IEND=1434
      IF(MLO.EQ.29)ISTART=1435
      IF(MLO.EQ.29)IEND=1490
      IF(MLO.EQ.30)ISTART=1491
      IF(MLO.EQ.30)IEND=1521
      IF(MLO.EQ.31)ISTART=1522
      IF(MLO.EQ.31)IEND=1557
      IF(MLO.EQ.32)ISTART=1558
      IF(MLO.EQ.32)IEND=1597
      IF(MLO.EQ.33)ISTART=1598
      IF(MLO.EQ.33)IEND=1612
      IF(MLO.EQ.34)ISTART=1613
      IF(MLO.EQ.34)IEND=1631
      IF(MLO.EQ.35)ISTART=1632
      IF(MLO.EQ.35)IEND=1643
      IF(MLO.EQ.36)ISTART=1644
      IF(MLO.EQ.36)IEND=1649
      IF(MLO.EQ.37)ISTART=1650
      IF(MLO.EQ.37)IEND=1650
   69 CONTINUE
C
C     PHI(LPHI2) IS THE PHI OF THE POINT TO THE LEFT OF OUT "TRUE" ORITAL POINT.
C
C     PHI(MPHI2) IS THE PHI OF THE POINT TO THE RIGHT OF OUR "TRUE" ORBITAL POINT.
C
      MPHI2=0
      DO 70 II=ISTART,IEND
      IF(MPHI2.NE.0)GO TO 70
      DIFF=PHI(II)-PHI0J
      IF(DIFF.GE.0.)MPHI2=II
      IF(DIFF.GE.0.)LPHI2=II-1
   70 CONTINUE
C
C     WE NOW HAVE 4 BOUNDING POINTS FOR THE JTH POINT...
C
C           LPHI1                   MPHI1
C                      TRUE POINT
C           LPHI2                   MPHI2
C
C
C     THETA VALUES MUST BE FOUND FOR LPHI1, LPHI2, MPHI1, AND MPHI2.
C
C     THE THETA VALUE CORRESPONDING TO EACH POINT WILL BE...
C     THETA FOR LPHI1 = THLP1.
C     THETA FOR LPHI2 = THLP2.
C     THETA FOR MPHI1 = THMP1.
C     THETA FOR MPHI2 = THMP2.
C
C     THE FOLLOWING LOOP ASSIGNS THE PROPER THETA VALUES.
C
```

```
C
      DO 80 IIII=1,4
      IF(IIII.EQ.1)POINT=LPHI1
      IF(IIII.EQ.2)POINT=LPHI2
      IF(IIII.EQ.3)POINT=MPHI1
      IF(IIII.EQ.4)POINT=MPHI2
      IF((POINT.GE.0).AND.(POINT.LE.72))THET=TH(1)
      IF((POINT.GE.73).AND.(POINT.LE.144))THET=TH(2)
      IF((POINT.GE.145).AND.(POINT.LE.215))THET=TH(3)
      IF((POINT.GE.216).AND.(POINT.LE.345))THET=TH(4)
      IF((POINT.GE.346).AND.(POINT.LE.353))THET=TH(5)
      IF((POINT.GE.354).AND.(POINT.LE.418))THET=TH(6)
      IF((POINT.GE.419).AND.(POINT.LE.480))THET=TH(7)
      IF((POINT.GE.481).AND.(POINT.LE.539))THET=TH(8)
      IF((POINT.GE.540).AND.(POINT.LE.594))THET=TH(9)
      IF((POINT.GE.595).AND.(POINT.LE.645))THET=TH(10)
      IF((POINT.GE.646).AND.(POINT.LE.691))THET=TH(11)
      IF((POINT.GE.692).AND.(POINT.LE.732))THET=TH(12)
      IF((POINT.GE.733).AND.(POINT.LE.759))THET=TH(13)
      IF((POINT.GE.769).AND.(POINT.LE.798))THET=TH(14)
      IF((POINT.GE.799).AND.(POINT.LE.823))THET=TH(15)
      IF((POINT.GE.824).AND.(POINT.LE.842))THET=TH(16)
      IF((POINT.GE.843).AND.(POINT.LE.854))THET=TH(17)
      IF((POINT.GE.855).AND.(POINT.LE.860))THET=TH(18)
      IF(POINT.EQ.861)THET=TH(19)
      IF((POINT.GE.862).AND.(POINT.LE.933))THET=TH(20)
      IF((POINT.GE.934).AND.(POINT.LE.1004))THET=TH(21)
      IF((POINT.GE.1005).AND.(POINT.LE.1074))THET=TH(22)
      IF((POINT.GE.1075).AND.(POINT.LE.1142))THET=TH(23)
      IF((POINT.GE.1143).AND.(POINT.LE.1207))THET=TH(24)
      IF((POINT.GE.1208).AND.(POINT.LE.1269))THET=TH(25)
      IF((POINT.GE.1270).AND.(POINT.LE.1328))THET=TH(26)
      IF((POINT.GE.1329).AND.(POINT.LE.1383))THET=TH(27)
      IF((POINT.GE.1384).AND.(POINT.LE.1434))THET=TH(28)
      IF((POINT.GE.1435).AND.(POINT.LE.1481))THET=TH(29)
      IF((POINT.GE.1482).AND.(POINT.LE.1521))THET=TH(30)
      IF((POINT.GE.1522).AND.(POINT.LE.1557))THET=TH(31)
      IF((POINT.GE.1558).AND.(POINT.LE.1587))THET=TH(32)
      IF((POINT.GE.1588).AND.(POINT.LE.1612))THET=TH(33)
      IF((POINT.GE.1613).AND.(POINT.LE.1631))THET=TH(34)
      IF((POINT.GE.1632).AND.(POINT.LE.1643))THET=TH(35)
      IF((POINT.GE.1644).AND.(POINT.LE.1649))THET=TH(36)
      IF(POINT.EQ.1650)THET=TH(37)
C
C     THET IS THETA FOR POINT.
C
      IF(IIII.EQ.1)PHLP1=THET
      IF(IIII.EQ.2)PHLP2=THET
      IF(IIII.EQ.3)PHMP1=THET
      IF(IIII.EQ.4)PHMP2=THET
   80 CONTINUE
C
C
C
C     FIND WHICH [illegible] POINT J.
C
      SLPHI1=SQ[illegible]
```

```
      DMPHT1=SQRT((PHIOJ-PHI(MPHT1))**2.+(THETOJ-THMP1)**2.)
      DLPHT2=SQRT((PHIOJ-PHI(LPHT2))**2.+(THETOJ-THLP2)**2.)
      DMPHT2=SQRT((PHIOJ-PHI(MPHT2))**2.+(THETOJ-THMP2)**2.)
      IF((DLPHT1.LT.DMPHT1).AND.(DLPHT1.LT.DLPHT2).AND.
     C(DLPHT1.LT.DMPHT2))MIN=LPHT1
      IF((DMPHT1.LT.DLPHT1).AND.(DMPHT1.LT.DLPHT2).AND.
     C(DMPHT1.LT.DMPHT2))MIN=MPHT1
      IF((DLPHT2.LT.DLPHT1).AND.(DLPHT2.LT.DMPHT1).AND.
     C(DLPHT2.LT.DMPHT2))MIN=LPHT2
      IF((DMPHT2.LT.DLPHT1).AND.(DMPHT2.LT.DMPHT1).AND.
     C(DMPHT2.LT.DLPHT2))MIN=MPHT2
C
C   SO THE SPHERE OF OPERATIONS POINT NEAREST THE JTH ORBITAL POINT IS POINT
C     MIN, WITH COORDINATES X(1,MIN), Y(1,MIN), Z(1,MIN), PHI(MIN), AND TH.
C
C   SO MIN IS STORED AS AN INTEGER VALUE IN THE MATRIX ORBITS(I,J)=MIN.
C
C
C   IF THE MOMENTUM VECTOR IS A POINT 73 THRU 961, ADJUST THE ROW NUMBER
C   TO FIT INTO THE ORBITS MATRIX.
C
      IF(M.LE.36)IA=I
      IF(M.GE.73)IA=I-36
      ORBITS(IA,J)=MIN
      IF(IO.NE.IA)PRINT*,"***** NEW ORBIT *****"
      IF(IO.NE.IA)PRINT*," "
      IF(IO.NE.IA)PRINT*," "
      PRINT*,"ORBITS(",IA,",",J,")= ",MIN
      IO=IA
 99   CONTINUE
 100  CONTINUE
      IF(M.EQ.1)GO TO 1
      STOP
      END
```

D. HELBASE Matrices

$$TIME_{50x4} = \begin{bmatrix} \text{Weapon Selection Number} & \text{Cycles Used} & \text{TAVAIL} & \text{XM} \\ 1 & & & \\ 2 & & & \\ \cdot & & & \\ \cdot & & & \\ \cdot & & & \\ 50 & & & \end{bmatrix}$$

$$\underset{825x36}{ORBITS} = \begin{array}{c} \begin{bmatrix} \text{Point Numbers in the Ith Orbit} \\ 1 \\ 2 \\ \cdot \\ \cdot \\ \cdot \\ 825 \end{bmatrix} \end{array} \text{Orbit Number}$$

$$\underset{50x6}{HELSEL} = \begin{bmatrix} \text{Weapon Type} & a & e & i & \Omega & \omega \\ & & & & & \\ & & & & & \end{bmatrix}$$

$$\underset{1650}{PHI} = \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \cdot \\ \cdot \\ \cdot \\ \varphi_{1650} \end{bmatrix}$$

$$\underset{37}{TH} = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \cdot \\ \cdot \\ \theta_{37} \end{bmatrix}$$

$$\underset{14x10}{T} = \begin{bmatrix} \text{Target Type Number} & a & e & i & \Omega & \omega & a & b & c & \text{XM} \\ & & & & & & & & & \end{bmatrix}$$

$$TAROPP_{14} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ \cdot \\ \cdot \\ \cdot \\ 4 \end{bmatrix} \quad \text{(1st Column of "T" Matrix)}$$

$$X_{5,1650},\ Y_{5,1650},\ Z_{5,1650} = \begin{array}{c} \text{Sphere of Operations Point Number} \\ \left[\begin{array}{c} \\ \text{(Cartesian Coordinate Values)} \\ \\ \end{array} \right] \end{array} \text{Weapon Type}$$

$$PATH_{5x825} = \begin{array}{c} \text{Orbits or Latitudes} \\ \left[\begin{array}{c} \text{(Path Average Target System} \\ \text{Sighting Efficiency Values)} \end{array} \right] \end{array} \text{Weapon Type}$$

$$XT_{14},\ YT_{14},\ \text{or } ZT_{14} = \begin{bmatrix} \\ \\ \end{bmatrix} \text{Target Numbers} \quad \text{(Cartesian Coordinate Values)}$$

$$XW_{50},\ YW_{50},\ \text{or } ZW_{50} = \begin{bmatrix} \\ \\ \end{bmatrix} \text{Weapons Selected} \quad \text{(Cartesian Coordinates of the Weapons Selected by Optimize)}$$

$$SUMEFF_{5x1650} = \begin{array}{c} \text{Sphere of Operations Point} \\ \left[\begin{array}{c} \text{(Values of Average Target} \\ \text{System Sighting Efficiency)} \end{array} \right] \end{array} \text{Weapon Type}$$

$$\underset{11\times5}{\text{WEAPON}} = \begin{bmatrix} \lambda_1 & \cdots & \lambda_5 \\ IO_1 & & \\ WO_1 & & \\ DELTTM_1 & & \\ DELTDM_1 & & \\ DELTRM_1 & & \\ RANMAX_1 & & \\ PF_1 & & \\ MODENO_1 & & \\ ALT_1 & & \\ SIG_1 & & SIG_5 \end{bmatrix}$$

$$\underset{4\times4}{\text{MISSION}} = \begin{bmatrix} \begin{array}{l} \text{Target} \\ \text{Type} \\ \text{Number} \end{array} & \begin{array}{l} \text{Target} \\ \text{Type} \\ \text{Negation} \\ \text{Percentage} \end{array} & \begin{array}{l} \text{Target} \\ \text{System} \\ \text{Negation} \\ \text{Time} \end{array} & \text{Priority} \\ & & & \\ & & & \end{bmatrix}$$

$$\underset{4\times3}{\text{TACTIC}} = \begin{bmatrix} \begin{array}{l} \text{Target} \\ \text{Type} \\ \text{Number} \end{array} & \begin{array}{l} \text{Firing} \\ \text{Priority} \end{array} & \begin{array}{l} \text{Irradiation} \\ \text{Time Sorting} \\ \text{Choice} \end{array} \\ & & \\ & & \end{bmatrix}$$

$$\underset{50\times14}{\text{BATTEF}} = \begin{array}{c} \begin{bmatrix} \begin{array}{llll} \text{Targets} & & & \\ 1 \quad 2 & \cdots & & 14 \end{array} \\ \\ \text{(Inverse Irradiation Times)} \\ \\ \end{bmatrix} \text{Weapons} \end{array}$$

$$\underset{50\times14}{\text{BATEF2}} = \begin{bmatrix} \begin{array}{llll} \text{Targets} & & & \\ 1 \quad 2 & \cdots & & 14 \end{array} \\ \\ \begin{array}{l} \text{(Inverse Irradiation Times} \\ \text{ of Targets of a Given Firing} \\ \text{ Priority)} \end{array} \end{bmatrix}$$

VITA

Captain Jeffrey L. Dutton was born on 29 September 1946 in Elsinore, California. Previous educational background includes a Bachelor of Science degree in Aerospace Engineering from the University of Arizona and several graduate courses from Ohio State University. He is a 1971 Distinguished Graduate of OTS, finished in the Top Third of his 1975 SOS class, and accepted a regular commission in 1974. He was assigned as an Astronautical Engineer and a Foreign Space Weapons Systems Analyst at the Foreign Technology Division from 1972 to 1974. After a voluntary career broadening tour as a missile combat crew member, he served as an Acquisition Project Officer and a Program Manager in the Aeronautical Systems Division.